Report No. CG-D-18-96

TEST TANK EVALUATION OF A FREQUENCY-SCANNING, MICROWAVE RADIOMETER TO ESTIMATE OIL SLICK THICKNESS AND PHYSICAL PROPERTIES

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FINAL REPORT

APRIL 1996

Prepared for:

U.S. Department of Transportation
United States Coast Guard
Office of Research and Development
Washington, DC 20593-0001

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-18-96		

4. Title and Subtitle	5. Report Date
Test Tank Evaluation Of A Frequency-Scanning, Microwave Radiometer to Estimate Oil Thickness And Physical Properties	April 1996
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
T.J. Murphy, O.B. McMahon, G.L. Hover	R & DC 10/96
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Lincoln Laboratory Mass. Institue of Technology 244 Wood Street Lexington, MA 02173-9108 USCG Research and Development Center 1082 Shennecosset Road Groton, CT 06340-9096	11. Contract or Grant No. F19628-95-C-0002
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation United States Coast Guard Office of Research and Development Washington, D.C. 20593-0001	Final Sept. 1994 - Feb. 1996
	14. Sponsoring Agency Code

15. Supplementary Notes This report is the second documenting U.S. Coast Guard sponsored development and testing of a frequency-scanning microwave radiometer for oil slick thickness measurement. The R & D Center's COTR and technical POC is Gary Hover, 860-441-2818.

16. Abstract

This report describes the testing of a 26 - 40 GHz (Ka-band) Frequency Scanning Radiometer (FSR) at OHMSETT (the National Oil Spill Response Test Facility) to evaluate the instrument's ability to detect and measure the thickness of oil films on water. Measurement variables were oil type, oil thickness, and wave conditions. The results indicate that the FSR was able to reliably measure oil thickness under calm conditions and, in some cases, under mild wave conditions. Future hardware development should include (1) a multichannel upgrade to the Ka-band FSR to decrease the data acquisition interval, and (2) the development of a proof-of-concept W-band (75 - 110 GHz) FSR to measure thinner films. After laboratory testing, these instruments should be evaluated at OHMSETT. Included in the Appendices to this report are all of the radiometric brightness temperature (T^B) versus measurement frequency plots for the data collected at OHMSETT.

17. Key Words	18. Distribution Statement
Radiometry, Oil Spill Remote Sensing, Microwave Radiometer, Oil Slick Thickness Measurement	Document is available to the U.S. public through the National Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. SECURITY CLASSIF. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

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METRIC CONVERSION FACTORS

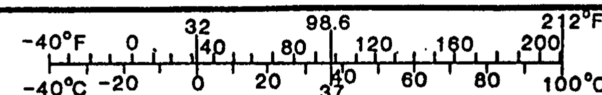
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (WEIGHT)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (EXACT)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (WEIGHT)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (EXACT)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

This report documents the testing of the 26 - 40 GHz (Ka-band) Frequency Scanning Radiometer (FSR) performed at the OHMSETT Facility over the period 10 -19 October 1994. These tests were performed to assess the ability of the FSR to measure oil-on-water thicknesses in an outdoor facility where the oil type, oil thickness, and wave conditions can be controlled.

Prior to the experiment at OHMSETT, the FSR was modified to support the testing at this facility. The modifications to the FSR are described, and results of the re-validation testing of the instrument are presented.

The test variables and conditions at OHMSETT are described as well as the daily activities. Over 800 measurement sweeps were collected during the test. Dyed diesel oil, crude oil, and oil/water emulsions were measured under calm, wave, and chop conditions. A "blind" thickness test was also performed. Results of the tests indicate that the FSR is able to reliably measure oil thicknesses under calm conditions, and under some light wave conditions. Results and analysis of each of the measurement conditions is included. Plots and comments concerning each data file collected as part of the test are included in the appendices.

Post collection analysis revealed that oil thicknesses are easier to compare when a smoothed data curve is superimposed over the actual data for comparison with the theoretical predictions. An ad-hoc oil thickness estimation algorithm was developed to assist with the analysis effort. The results of this algorithm show promise for the automatic recognition of oil thickness based on the FSR measurements although further developmental work is needed.

The results of oil measurements under dynamic wave conditions indicate that a faster measurement time interval is necessary. The FSR collects data over a 12

second measurement sweep, and the surface conditions change during this time interval. A radiometer that has the same receiver channel characteristics, and that can collect data over a 1 second interval (or less) is needed. This can be accomplished by designing a multichannel (parallel receiver channels) Ka-band radiometer. After laboratory verification and testing, this multichannel radiometer should be tested at OHMSETT under test conditions similar to those measured during this experiment.

Some difficulties were experienced with reliably measuring oil thicknesses less than 2.0 mm using the available Ka bandwidth. These measurement curves appear as straight lines, not as quasi-sinusoidal curves, and can be difficult to match unambiguously with the theoretical predictions. More instrument bandwidth is required to reliably measure these thin films. Instrument bandwidth may be expandable to the next low atmospheric absorption window in the 75 - 110 GHz (W-band) frequency range. To aid in the future measurement of thin films, development of a proof-of-concept W-band FSR is recommended.

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CHAPTER 1
INTRODUCTION

The United States Coast Guard has a requirement to develop an all weather capability to remotely measure oil slick thicknesses. Passive millimeter wave and microwave-radiometry (MWR) has been identified as the only sensor technology that is potentially capable of all-weather oil slick thickness determination. Previous MWR designs, which operated at fixed frequencies, have encountered significant uncertainties in thickness due to inherent ambiguities in fixed-frequency radiometric data.

Under U. S. Coast Guard sponsorship, MIT Lincoln Laboratory (MIT/LL) has developed and patented a unique approach to oil thickness sensing with a sound theoretical basis, that takes advantage of recent developments in commercially available millimeter wave components. This approach involves the scanning of the radiometric brightness temperature of an oil slick patch over a wide frequency range to obtain a continuous curve of the slick signature data (i.e., radiometric temperatures). From these signatures the spill thickness can be determined uniquely without the ambiguity associated with fixed frequency radiometry. Previous measurements, conducted under highly controlled outdoor laboratory conditions, have validated the Frequency Scanning Radiometer (FSR) concept and demonstrated potential utility for field applications (reference 1). Additional oil thickness measurements in an outdoor wave tank facility where oil type, quantity, and location relative to the instrument field of view can be controlled while simulating a more realistic marine environment, including sea state, were undertaken at OHMSETT, the National Oil Spill Response Test Facility (formerly referred to as the Oil and Hazardous Materials Simulated Environmental Test Tank, hence, OHMSETT). The results of the outdoor wave tank facility tests are essential to determining the future practicality and cost-effectiveness of developing an operational FSR sensor.

The OHMSETT facility, located on the Earle Naval Weapons Station and operated by the U.S. Minerals Management Service in Leonardo, NJ, is an outdoor facility capable of producing a variety of controlled water wave conditions and presenting a variety of oil and emulsion-on-water targets, several

meters in diameter, to the instrument. This facility was used during October 1994 to support the FSR tests.

An earlier report (reference 1) described the FSR design, validation, and initial testing using homogeneous and non-homogeneous oil thicknesses under laboratory conditions. Chapter 2 of this report describes the modifications to the FSR equipment and pre-test validation to support the OHMSETT data collection. Chapter 3 outlines the test program at OHMSETT. Chapter 4 provides an analysis of the test results. Based on the analysis of OHMSETT test data, chapter 5 provides conclusions concerning the potential for using FSR technology in oil spill response operations and provides recommendations for future work.

CHAPTER 2
FSR MODIFICATION AND VALIDATION

The FSR laboratory prototype described in reference 1 was modified for outdoor testing at OHMSETT and for shipping to sponsor directed demonstrations. Section 2.1 describes the hardware and software modifications to the instrument. After modification, validation tests were performed to verify system operation. Section 2.2 describes the validation tests and results.

2.1 FSR MODIFICATION

The FSR laboratory prototype was modified to reliably collect data at OHMSETT in a variety of environmental conditions. The modifications to the FSR equipment include (1) installing a hot load for calibration, (2) mounting the receiver electronics inside a protective structure, (3) installing a bore-sighted finder scope for manual antenna pointing and, (4) rack-mounting the sweep oscillator and supporting electronics equipment. The remainder of this section will describe the details of each of these modifications. The system block diagram is illustrated in Figure 2-1.

Calibration Hot Load. During the FSR proof-of-principle testing (reference 1), it was found that the FSR should be re-calibrated using a hot load on a regular basis during testing. The calibration was performed by manually introducing a hot load (a piece of microwave absorbing material at room temperature) in front of the antenna. It was obvious that having to manually introduce the hot load in front of the antenna on a regular basis could seriously compromise the instrument's operational feasibility. An internal calibration capability was necessary.

The purpose of the hot load calibration is to remove any effects of the amplifiers or mixers, due to drift, which would cause uncompensated changes in the measured brightness temperatures. Antenna effects have no influence on the hot load calibration procedure (assuming that the antenna beamwidth is fully covered by the material), so the introduction of a calibration source ahead of the mixer (on the antenna side of the mixer) is an acceptable calibration method.

An antenna acts as a terminated source ahead of the mixer, and with the antenna beamwidth filled with microwave absorbing material, the antenna 'sees' its ambient radiometric temperature as a terminated noise source. A waveguide termination, by design, is a terminated source, and radiometrically acts as a noise source at its ambient temperature. Thus, in the modified FSR configuration, a terminated waveguide was used instead of a manually-introduced hot load.

A low insertion loss waveguide switch serves as the mechanism to switch between the antenna and the calibration hot load. Figure 2-2 shows the configuration of the waveguide switch modification at the input to the waveguide mixer. The waveguide switch, in its normal condition, connects the antenna to the mixer; with the application of 28-Vdc, the switch changes position to connect the waveguide termination to the mixer input. The control of the switch was to be managed through the laptop computer software through an HPIB addressable HP-59306 relay actuator. However, during instrument verification tests, the HP-59306 failed, so the waveguide switch was controlled manually. (The relay actuator was acquired as excess property, at no cost to the program, and was not worth fixing after its failure.)

Receiver Electronics Telescope. As part of the modification to prepare the FSR for OHMSETT testing, the receiver electronics were installed in a "telescope" tube. The tube is a 10-inch diameter 30-inch long piece of gray PVC pipe with clear end caps installed. The receiver electronics components, consisting of the antenna, calibration hot load, waveguide switch, mixer, amplifiers, filters, detector and heat sink source and controller, are mounted on a rigid (wooden) structure form-fitted to the base of the pipe. Cables for power to the heater and receiver electronics, waveguide switch control, detector output, and local oscillator output are fed through the rear access plate; the antenna feed horn is fed through the front access plate.

The low-loss coaxial cable that connects the sweep oscillator with the receiver electronics is a constraining factor as to how far the tube can be located from the electronics rack. A new, longer coaxial cable was procured so that the mixer

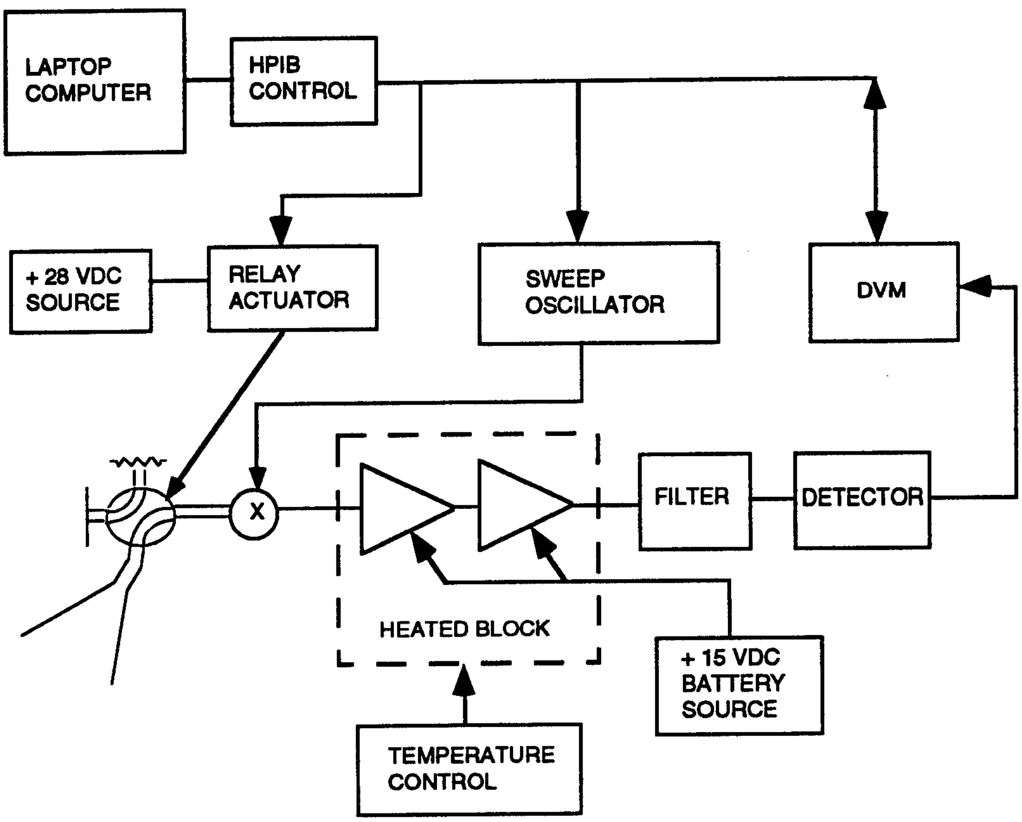

Figure 2-1 FSR Block Diagram

could be located in the telescope tube. Although the coaxial cable is considered low-loss, the attenuation through the cable must be taken into account, and sufficient power must be available at the mixer RF input. Under this constraint, the tube was mounted on top of the water resistant electronics cabinet.

Finder Scope. The initially proposed test plan included measurements from the camera tower at OHMSETT. This tower is approximately 30 feet above the water surface. The finder scope was installed to assist the operator in aiming the antenna telescope to the center of the oil pools. The finder scope is located on the back left side of the FSR telescope, and has a field-of-view similar to the antenna.

The antenna and finder scope were bore-sighted in the laboratory. The procedure used to align the antenna and finder scope was to aim the antenna to

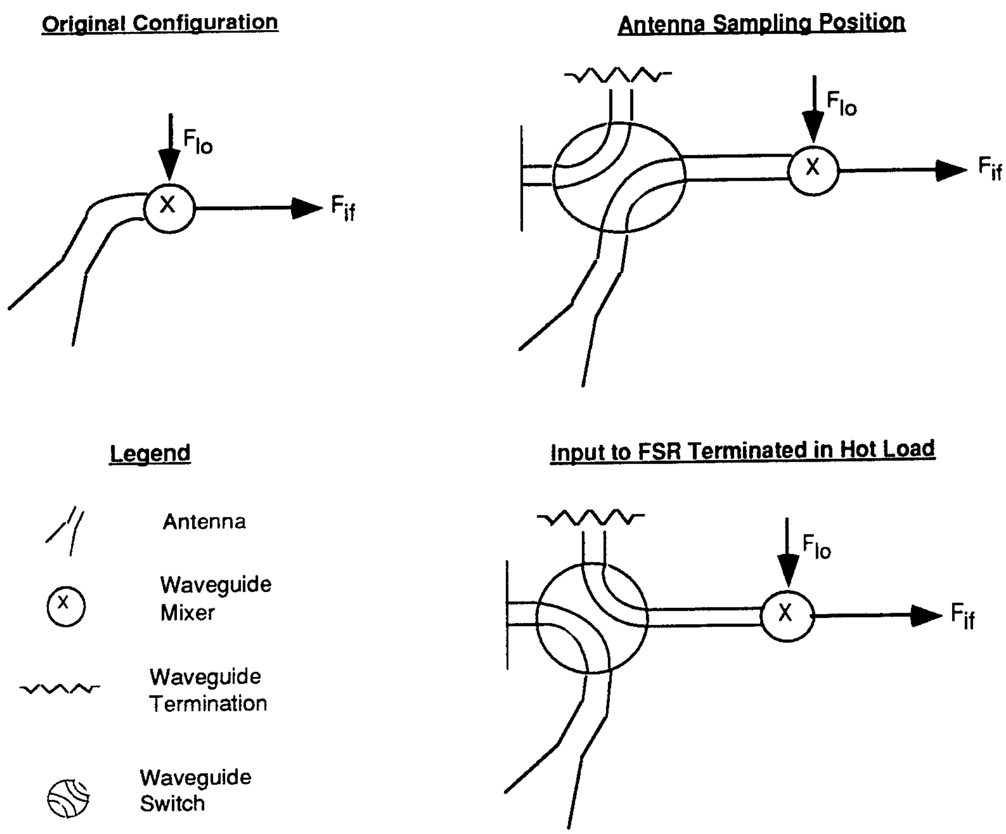

Figure 2-2 Waveguide Switch Configuration

obtain a peak response from the FSR to a hot load placed 30 feet away. With the antenna in this position, the finder scope was adjusted so that cross-hairs of the finder scope aligned with the hot load generator. Using the same procedure, a set of alignment marks were made on the tube end caps.

Because of fiscal constraints, the FSR measurements from the camera tower were not included in the final test plan. For measurements from the OHMSETT bridge, the alignment marks on the end caps were sufficiently accurate to aim the FSR telescope on the oil pool target.

Equipment rack-mount. To protect the laboratory instrumentation from adverse weather and excessive vibration, a water-resistant shock-mounted rack enclosure was procured. This rack houses the HP-8350 Sweep Oscillator,

HP-34401 Digital Voltmeter, HP-59306 Relay Actuator, the power supplies for the waveguide switch and receiver electronics, and the AC power distribution for the system. For convenience in transporting the system on site, the rack was outfitted with removable casters.

The top of the rack is at a suitable height for using the laptop computer. Additionally, the mounting bracket for the FSR telescope was attached to the top of the rack, making the FSR a self-contained instrument.

A padded equipment case was also procured for transporting the laptop computer and IO Tech interface.

2.2 FSR EQUIPMENT RE-VALIDATION TESTS

After the installation of the waveguide switch was completed, the response of the switched hot load was compared with that of a hot load in line with the antenna. Receiver noise tests showed that the switched hot load produced a response similar to that obtained using the previous method of manually introducing a hot load in front of the antenna. As expected, no loss of instrument sensitivity was detected after the installation of the waveguide switch and associated waveguide.

Prior to the transport of the FSR to OHMSETT, a set of uniform-layer oil thickness measurements was collected using the previously-developed laboratory test procedure and test tank. The tests consisted of two sets of two independent measurements of oil thicknesses ranging from 0.0 mm to 8.0 mm in steps of 0.5 mm. The complete set of FSR measurements taken as part of the equipment re-validation are shown in Appendix A; the results are shown in tabular form both in Appendix A and in Table 2-1. The results from the re-validation testing indicated that the FSR was operational and was ready for measurements at OHMSETT.

2.2.1 Analysis of Re-validation Test Results of 5 and 6 October 1994

Referring to tables 2-1 and 2-2, one finds four columns listing the oil thickness estimation results from data taken on 5 October 1994 and two columns listing the oil thickness estimation results from data collected on 6 October 1994. Table 2-1 contains the results of the visual analysis of the measured data, while table 2-2 contains the results of the oil thickness estimation algorithm. (The oil thickness estimation algorithm will be described in detail in Chapter 4.) The highlighted table entries in table 2-1 indicate a significant difference between the actual thickness and the visual analysis estimate; the highlighted table entries in table 2-2 indicate a significant difference between the algorithm-based estimate and the visual analysis results.

The first two columns, labeled with the 'A Ref' designation, use the first of two water measurements for background calibration. Note that all of the estimates seem reasonably well correlated with the actual intended oil layer thickness, except for the 0.5 mm estimates of 0.0 mm and the 1.0 mm estimates of 0.625 mm. These poor estimates stem from the fact that the measured water background seems high, possibly because the FSR is still 'warming up' after the hot/cold load calibration was performed. The bipolar transistor amplifiers must reach a stable temperature to prevent T^B drifts; as the transistors warm, their gain increases and if left uncorrected, the measured T^B would also increase.

The next two columns, labeled with the 'B Ref' designation, use the second of the two water measurements for the background calibration. Note that now the estimates of the 0.5 mm and 1.0 mm thicknesses seem more reasonable, while the 3.5 mm and 6.5 mm estimates are off. Referring to the actual plots in the Appendix, the 3.5 mm curve is difficult to separate from thin measurements because the T^B sinusoidal variation is at a minimum (i.e., very close to water) with a very low oscillation frequency (i.e., the curve is nearly flat except at the edges of the 26 - 40 GHz span). The 6.5 mm curve has sufficient shape for a trained FSR operator to recognize that the resulting curve from the oil thickness estimation algorithm is not a good fit, and that a thicker estimate is appropriate.

Again referring to tables 2-1 and 2-2, the final two columns summarize the results of the measurements performed on 6 October 1994. Water background measurements were performed, but were not recorded, hence, an assumption was made that the radiometric background was similar to the previous day. The 'A Ref' from 5 October 1994 was used as the water background reference for this data set. As described above, although this water measurement seemed high for the 5 October 1994 comparisons, the apparent background temperature for the 6 October measurements seemed warmer, and the 'A Ref' created a data set that had a better overall fit for the comparisons. All of the estimated thicknesses correlate well with the intended thickness except for the 1.5 mm measurements. In this case, the algorithm over-estimated the oil thickness.

This analysis shows that (1) the FSR must reach an equilibrium temperature state before measurements are performed, (2) a good background water measurement (no warm-up drift) is needed to reliably estimate thin oil film thicknesses, and, (3) for the most part, the oil thickness estimation algorithm results for curves with good 'shape' characteristics agree if a reasonable background water measurement is used.

Table 2-1

Visual Analysis Results of Oil Thickness For FSR Validation Tests

Actual Thickness (mm)	5 Oct. 94 Pass 1 (mm) A Ref	5 Oct. 94 Pass 2 (mm) A Ref	5 Oct. 94 Pass 1 (mm) B Ref	5 Oct. 94 Pass 2 (mm) B Ref	6 Oct. 94 Pass 1 (mm) Note 1	6 Oct. 94 Pass 2 (mm) Note 1
0.5	0.0	0.0	0.375	0.450	0.325	0.500
1.0	0.625	0.625	0.850	0.850	0.750	0.775
1.5	1.025	1.050	1.375	1.400	1.900	1.900
2.0	1.900	1.900	1.825	1.800	2.000	2.200
2.5	2.250	2.250	2.250	2.250	2.725	2.775
3.0	2.975	2.975	2.650	2.650	3.125	3.200
3.5	3.300	3.325	3.325	3.325	3.625	3.625
4.0	3.800	3.800	3.850	3.825	4.275	4.175
4.5	4.200	4.225	4.375	4.350	4.575	4.550
5.0	4.800	4.800	4.825	4.825	5.175	5.050
5.5	5.250	5.250	5.225	5.225	5.400	5.450
6.0	5.700	5.750	5.650	5.775	6.075	6.025
6.5 (Note 2)	6.300	6.325	6.300	6.325	6.500	6.500
7.0	6.775	6.750	6.800	6.800	6.900	6.850
7.5	7.175	7.225	7.250	7.250	7.350	7.325
8.0	7.775	7.775	7.775	7.775	7.925	7.900

Note 1 - Water measurements were taken but not recorded for 6 Oct. 94. Theoretical water background T^B measurements were assumed to be the same as 5 Oct. 94.

Note 2 - Although the files for 5 Oct. 94 are labeled as 6.6 mm, they were actually 6.5 mm oil thickness.

Table 2-2

Results of Oil Thickness Estimation Algorithm For FSR Validation Tests

Actual Thickness (mm)	5 Oct. 94 Pass 1 (mm) A Ref	5 Oct. 94 Pass 2 (mm) A Ref	5 Oct. 94 Pass 1 (mm) B Ref	5 Oct. 94 Pass 2 (mm) B Ref	6 Oct. 94 Pass 1 (mm) Note 1	6 Oct. 94 Pass 2 (mm) Note 1
0.5	0.0*	0.0*	0.375	0.450	0.325	0.500
1.0	0.625*	0.625*	0.850	0.850	0.750	0.775
1.5	1.025	1.050	1.375	1.400	2.200	2.175
2.0	2.200	2.200	1.825	1.800	2.200	2.200
2.5	2.525	2.525	2.250	2.250	2.725	2.775
3.0	2.975	2.975	2.650	2.650	3.125	3.200
3.5	3.300	3.300	0.600*	0.575*	3.600	3.625
4.0	3.650	3.650	3.850	3.825	4.275	4.175
4.5	4.200	4.175	4.375	4.350	4.575	4.550
5.0	4.800	4.800	4.825	4.825	5.200	5.050
5.5	5.300	5.275	5.225	5.200	5.400	5.450
6.0	5.750	5.750	5.650	5.650	6.075	6.025
6.5 (Note 2)	6.300	6.325	2.400*	2.400*	6.425	6.400
7.0	6.775	6.750	6.800	6.800	6.850	6.875
7.5	7.225	7.225	7.250	7.250	7.350	7.325
8.0	7.775	7.775	7.775	7.775	7.925	7.900

Note 1 - Water measurements were taken but not recorded for 6 Oct. 94. Theoretical water background T^B measurements were assumed to be the same as 5 Oct. 94.

Note 2 - Although the files for 5 Oct. 94 are labeled as 6.6 mm, they were actually 6.5 mm oil thickness.

* Indicates algorithm derived estimates that are very different from the actual thickness. The A Water Reference of 5 Oct. seemed warmer than the B reference; note that with the warmer reference, thin oil layers are estimated as lower values. Correlation only results give estimates of 3.375 mm (5 Oct. Pass 1 B Ref, 3.5 mm), 6.300/6.325 mm (5 Oct. Pass 1 & 2, B Ref, 6.5 mm), and 1.900/1.875 mm (6 Oct. Pass 1 & 2, 1.5 mm).

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CHAPTER 3

OHMSETT EXPERIMENT TEST DESCRIPTION

Chapter 3 describes the FSR data collection activity at OHMSETT over the period 11 October to 19 October 1994. Figure 3-1 is a photograph of the OHMSETT facility from the control tower looking south toward the wave generator; Figure 3-2 is a photograph from the wave generator looking north toward the control tower. Included in this chapter is a discussion of the test objective, initial tests performed upon arrival at OHMSETT to ensure that the FSR was operating properly, the FSR data collection with various oil slick targets, and the ground truth items available from OHMSETT.

3.1 TEST OBJECTIVE

The objective of the OHMSETT test program was to assess the ability of the FSR to measure oil thickness in a realistic environment in which sea conditions could be controlled. The test program was scheduled as four data collection days (in addition to a dry run day) over a two week period. The intent of this schedule was to use different oil types, quantities, wave conditions, and weather conditions to determine the practicality of further development of the FSR sensor.

Four data collection scenarios were planned, namely (1) uniform oil thicknesses under various wave conditions, (2) "patchy" oil under various wave conditions, (3) oil/water emulsions under various wave conditions, and (4) an open collection day which might be a collection under quite different weather conditions, a repeat day due to inconclusive results on a previous day, or an "unknown thickness" collection. The unknown thickness collection was chosen as the fourth day because the previous three collection days had produced understandable results, and the weather forecast for the time remaining at OHMSETT was for weather similar in nature to previous collection days.

3.2 OIL TYPE/TARGET DESCRIPTION

Three different types of oil were used during the OHMSETT tests. Each of the oil types was chosen for a particular characteristic, namely, (1) the ability to form thin uniform oil layers, (2) the ability to form stable "clumpy" oil targets, and, (3) the ability to form a stable emulsion. These oils are referred to as Type 1, Type 2, and Type 3 Oil, respectively. These oil types were used to form uniform oil targets, patchy oil targets and emulsified oil targets as described below.

Uniform Oil Target. A uniform thickness oil target consisted of a 3-meter diameter constrained oil pool containing Type 1 oil. As described in reference 2, Type 1 oil was planned to be RECCO 60 Oil. RECCO 60 has a moderately low specific gravity (0.91), and low viscosity. It is a mix of paraffinic and napthenic oils that will resist emulsification; however, it tended to form lens-shaped globs rather than uniform layers when introduced into the test pools. During initial testing, a decision was made to substitute diesel fuel oil for the RECCO 60 Oil as the type 1 oil since previous experience with diesel had shown its ability to form thin uniform oil films. During the dry run day, it was difficult to discern the nearly colorless diesel oil atop the water in the containment booms. A suggestion was made to add red dye colorant to the oil used for later tests; this suggestion was adopted after using the FSR to verify that the red dye did not alter the expected T^B signature.

The containment areas for thin oil (less than 2.0 mm) were filled by hand, i.e. delivering the correct quantity of oil using 5-gallon buckets. The thicker pools were filled using gravity feed from the storage tank on the main equipment boom, and metering the oil volume by measuring the change of level in the storage tank with a measuring stick. Figure 3-3 illustrates a typical dyed diesel oil pool under calm conditions.

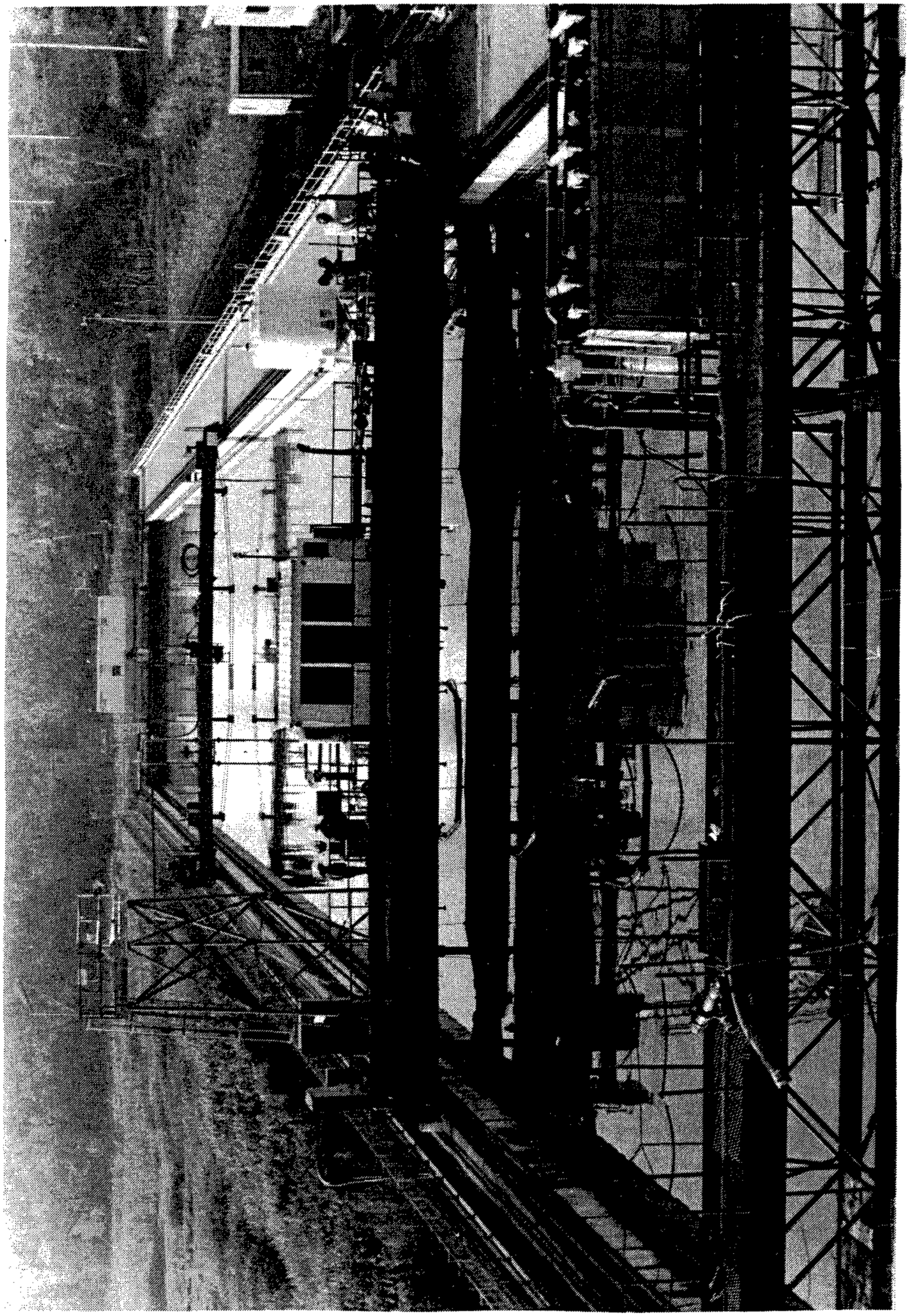

Figure 3-1 - Photo of OHMSETT facility from control tower looking south

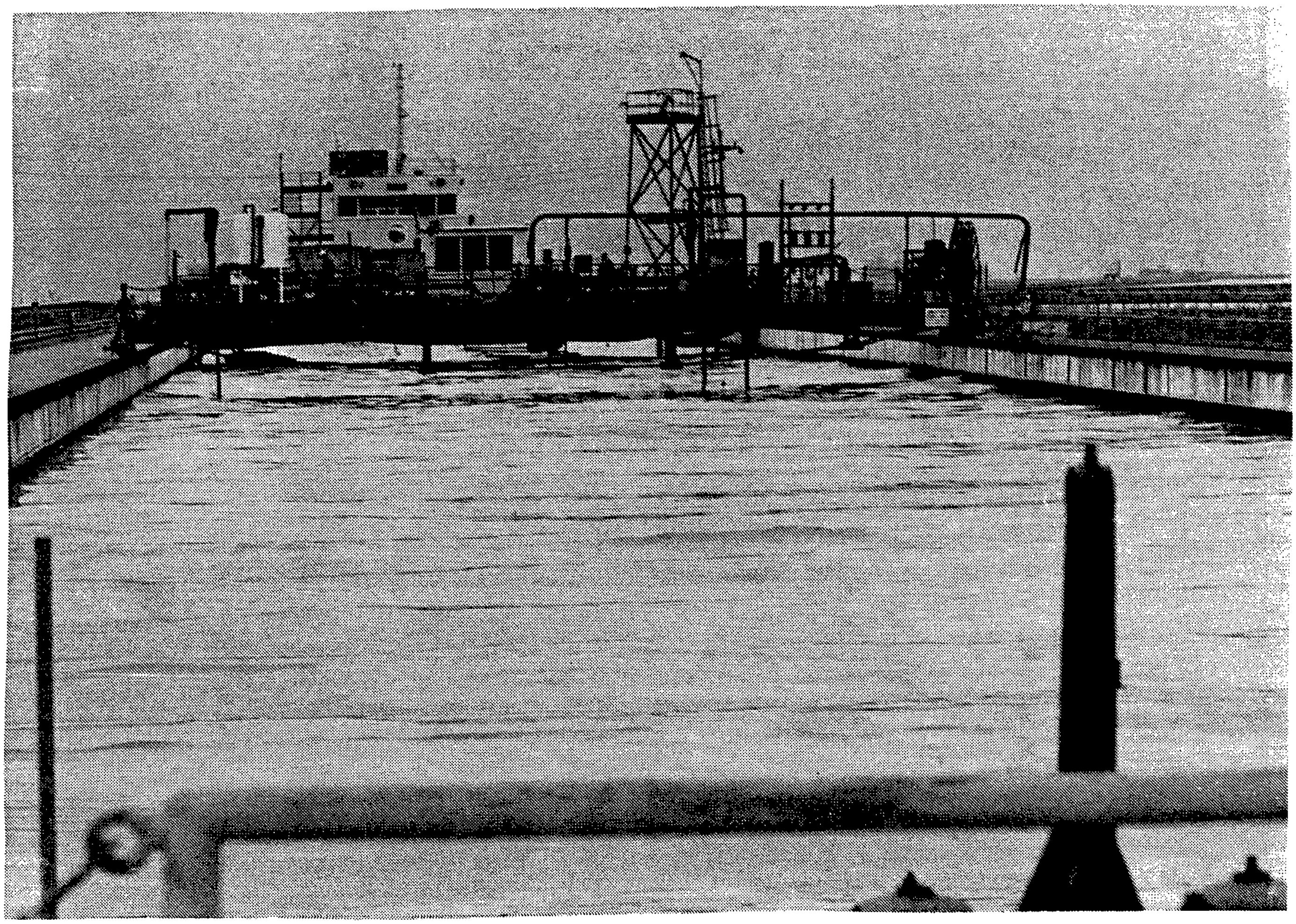

Figure 3-2 Photograph of OHMSETT Facility From Wave Generator Looking North

Patchy Oil Target. A patchy oil target consisted of a 3-meter diameter constrained area into which a volume of Type 2 oil was introduced. As described in reference 2, the type 2 oil used was Alberta Sweet Mixed Blend, also referred to as Federated Crude Oil. The oil was obtained from the ESSO test basin in Calgary Alberta Canada. The oil, when received, was 15% weathered. Even though the oil was weathered, it still contained a high percentage of volatiles. It was estimated that 25% of the volume of the oil pools would evaporate overnight, so initially, the pools were overfilled by 25%.

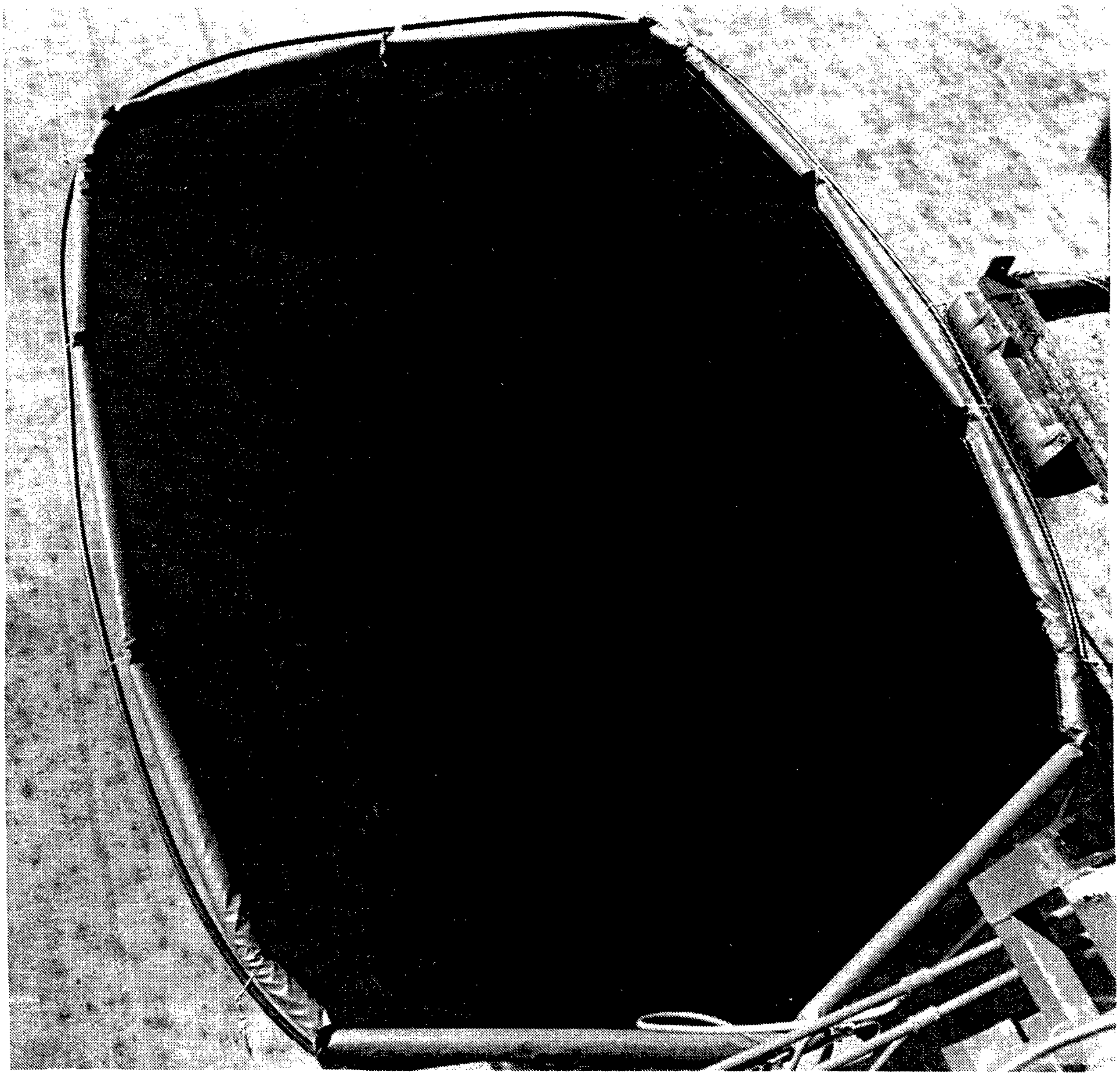

Figure 3-3 Photograph of Type 1 Oil Target Under Calm Conditions

The quantity (volume) of Type 2 oil poured into the area was equivalent to a 2.5 mm thickness covering the indicated percentage of area within the 3-meter diameter pool with 25% more oil added due to expected evaporation. The oil did not distribute itself exactly as desired in the test plan; the oil in the low percentage volume pools tended to stay bound together forming a separate oil area within the pool. Because the oil tended to stay together, FSR measurements were concentrated in the oil pools rather than the center of the containment area. After settling overnight, and obtaining a uniform thickness

measurement, the oil was broken up manually, and patchy measurements were obtained. As the oil warmed during the day, some of the lighter components leached out of the oil pool, onto the water in the containment area. Figure 3-4 illustrates a typical type 2 oil pool under calm conditions. Because of the variations of oil conditions for this type of oil, FSR signatures must be examined against the photographic and video images of the targets during actual time of data collection.

Emulsified Oil Target. An emulsified oil target consisted of a 3-meter diameter constrained area into which a fixed quantity of a stable, emulsified mixture of water and Type 3 oil was poured. As described in reference 2, this is a heavy phase oil from the OHMSETT centrifuge separation process. This oil has a rich concentration of polar molecules and tends to form stable emulsions.

The emulsion contained a specified percentage of water by volume. The intent of creating emulsion targets was to introduce enough of the oil/water mixture into the 3-meter diameter target pool to cover the entire surface to the thickness indicated. When the correct volume of oil was poured into the target pools, however, the emulsion tended to stay clumped together in a thick mass and remain near the edges of the containment area. Figure 3-5 illustrates a typical type 3 oil pool under calm conditions.

The emulsion was created using oil and water pumped through a recirculating water jet, as shown in Figure 3-6, until the emulsion had formed a consistent texture The 20% emulsion was made from 4.6 gallons of basin water and 26 gallons of type 3 oil. The 40% emulsion consisted of 26 gallons of basin water and 14.7 gallons of type 3 oil. (Reference 2)

Figure 3-4 Photo of Type 2 Oil Target under calm conditions

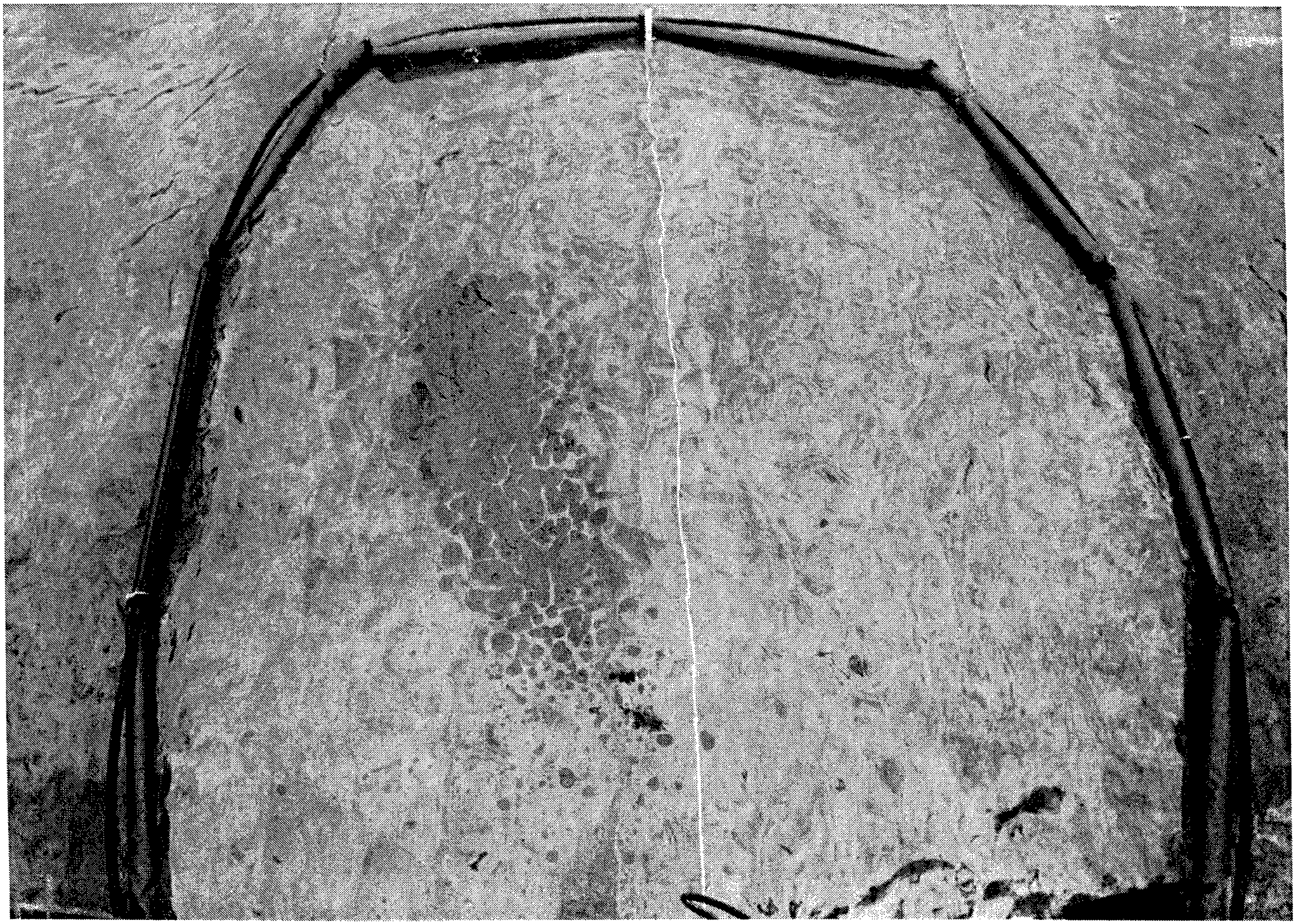

Figure 3-5 Photo of Type 3 Oil Target under calm conditions

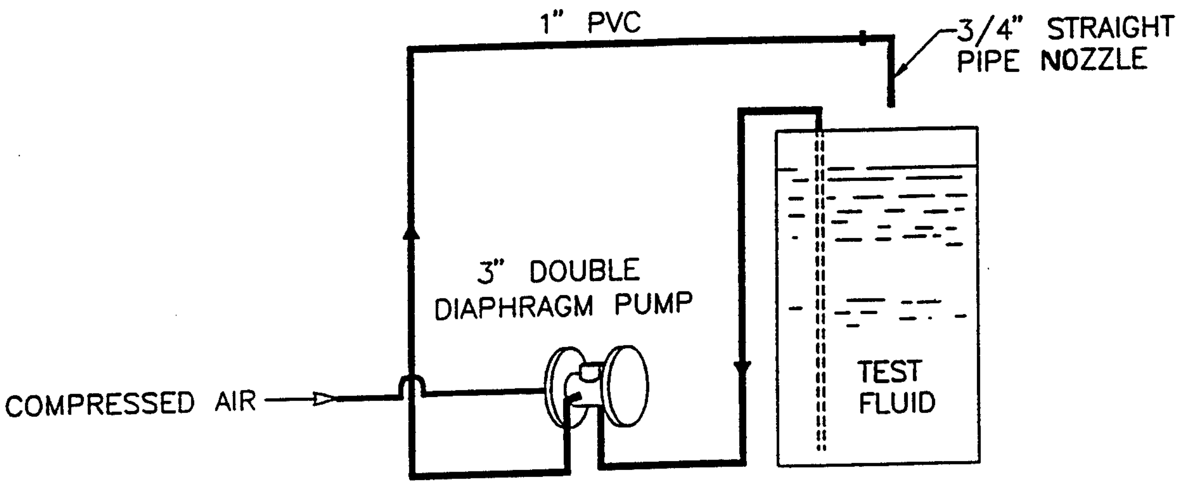

Figure 3-6 OHMSETT Oil/Water Emulsion Maker

3.3 WAVE CONDITION DESCRIPTION

During initial test planning stages, eight different wave conditions were specified. The eight specified conditions were cut back to five wave conditions that could be easily accommodated at OHMSETT. The five wave conditions chosen were (1) calm, (2) small waves, (3) medium waves, (4) harbor chop 1, and, (5) harbor chop 2.

Wave conditions at OHMSETT are specified by the length of the wave generator stroke, the frequency of stroke oscillation, and whether the beaches are up or down. The beaches, located at the north end of the OHMSETT facility, act to absorb the wave energy when they are in the up position; when the beaches are down, reflected wave energy creates a confused sea state (harbor chop condition). The wave height and period are related to the stroke and the frequency. The frequency of the wave generator is controlled through the wave generator control panel located in the control tower. The frequency can easily be changed while waves are still present in the tank. Changing the stroke requires a physical change of the length of the wave generator lever arm. For the safety of personnel involved in this task, the waves in the tank are allowed to

subside, before the lever arm length is modified. Obviously, waves that can be specified by changing only the frequency or the position of the beach are the easiest to obtain.

The parameters associated with each test wave condition were as follows:

Calm. In the calm condition, no waves were being generated. The surface conditions of the water were dictated by the ambient weather conditions. Figure 3-7 illustrates pools of type 2 oil under calm conditions.

Small Waves. Small waves were generated utilizing beaches up, and using a stroke of 1.5 inches at a frequency of 18 cycles per minute. This generated waves of approximately 2-inches peak to trough, at a frequency of 0.3 cycles/second. Figure 3-8 illustrates pools of type 1 oil in small waves. These small waves will be referred to as Wave Condition 1 in the remainder of the text.

Medium Waves. Medium waves were generated utilizing beaches up, and using a stroke of 1.5 inches at a frequency of 38 cycles per minute. This generated waves of approximately 4.5-inches peak to trough, at a frequency of 0.6 cycles/second. Figure 3-9 illustrates pools of type 1 oil in medium waves. In this condition, occasional loss of small amounts of oil from the test pools was observed. These waves will be referred to as Wave Condition 2 in the remainder of the text.

Harbor Chop 1. Harbor chop 1 condition was created by dropping the beaches, and using a stroke of 1.5 inches at a frequency of 30 cycles per minute. This generated a confused sea state with peak-to-trough wave heights averaging 3-inches. In this condition there were no waves breaking. Figure 3-10 illustrates pools of type 1 oil in harbor chop 1 wave conditions.

Harbor Chop 2. Harbor chop 2 condition was created by dropping the beaches, and using a stroke of 1.5 inches at a frequency of 40 cycles per minute. This generated a confused sea state with peak-to-trough wave heights averaging 5.5-inches. In this condition there were some breaking waves. Figure 3-11 illustrates pools of type 1 oil in harbor chop 1 wave conditions. Significant amounts of oil were occasionally lost from the test pools in this condition.

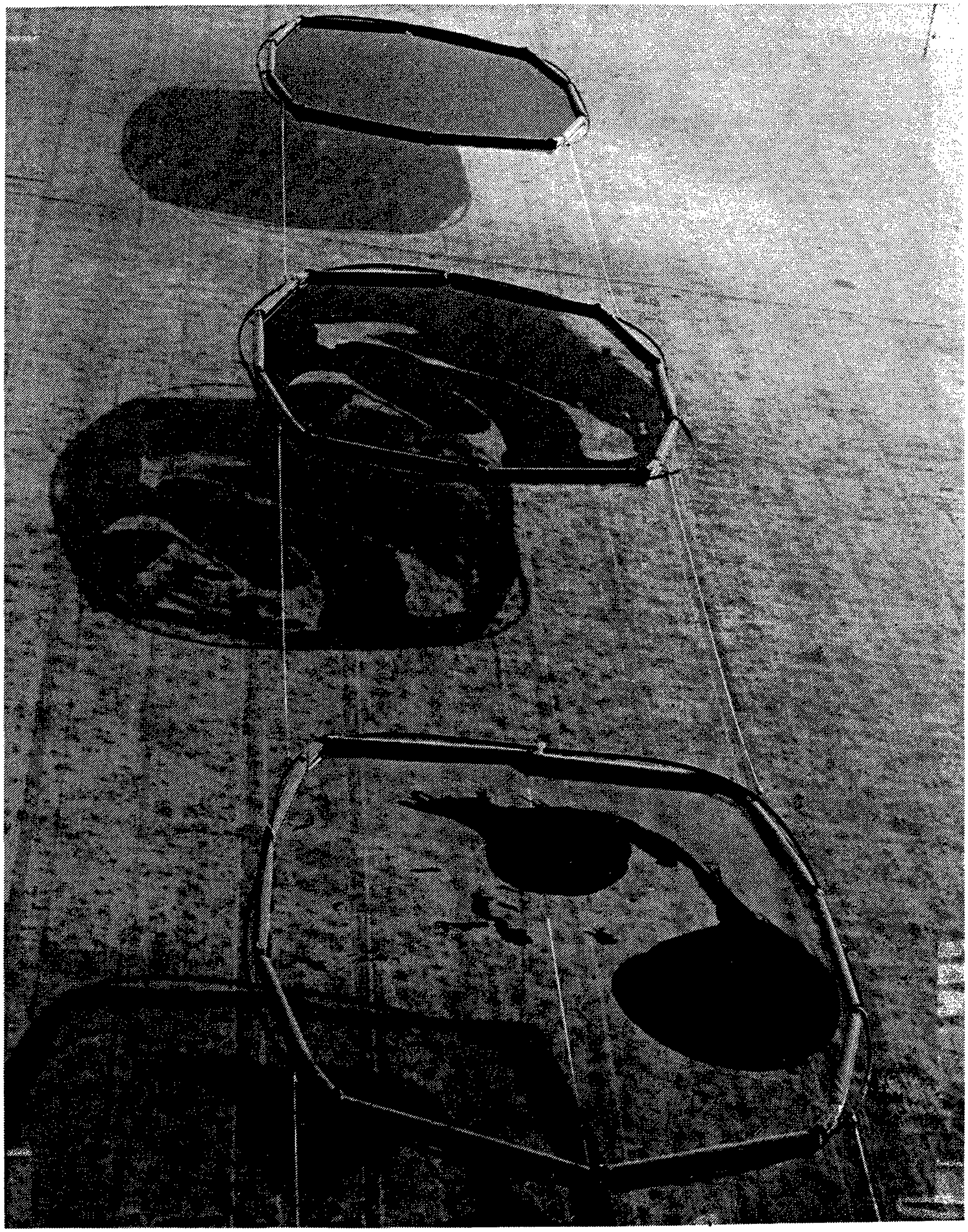

Figure 3-7 Photograph of Type 2 Oil Pools Under Calm Conditions

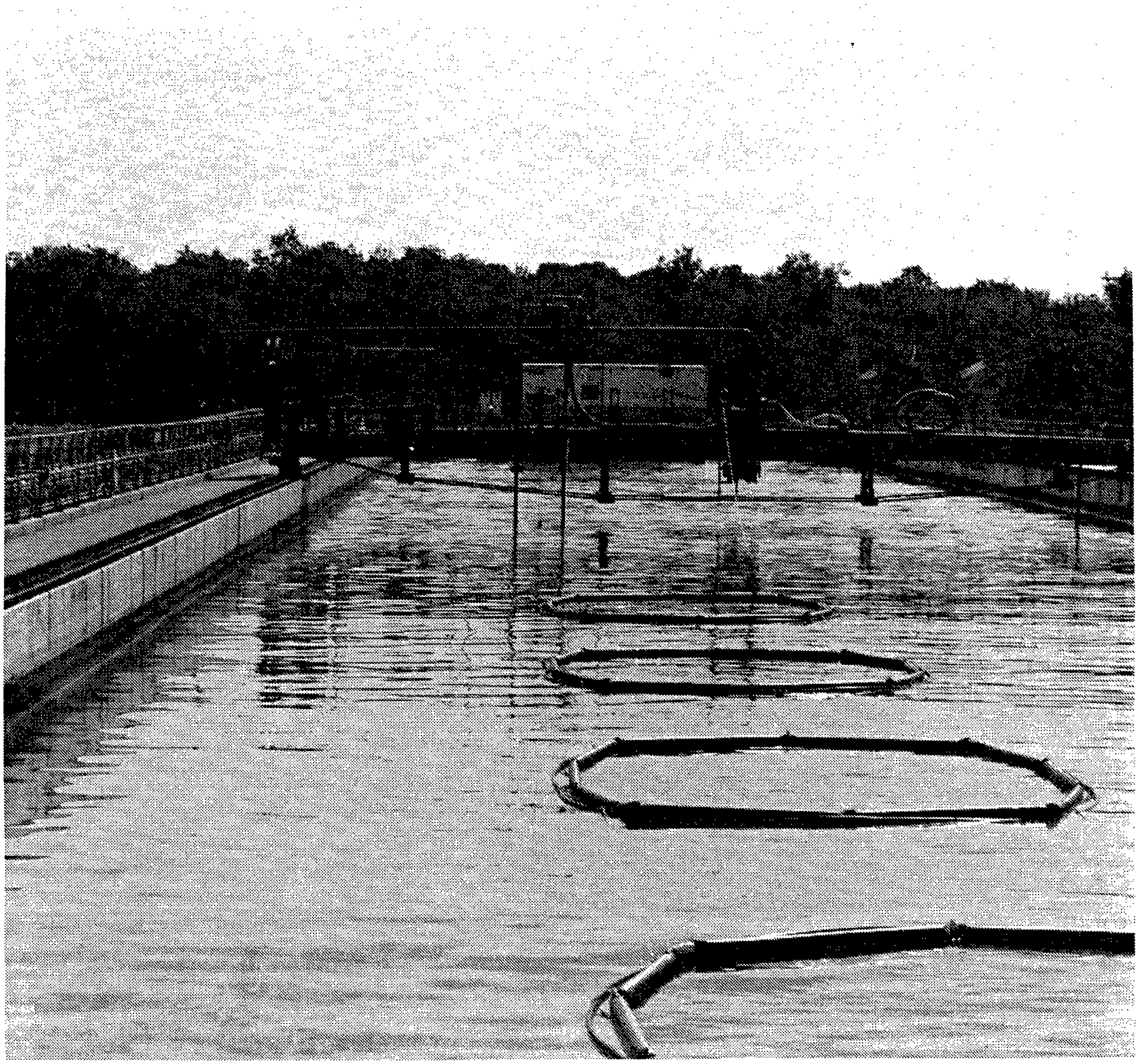

Figure 3-8 Photograph of Type 1 Oil Pools Under Small Wave Conditions, Wave Condition 1

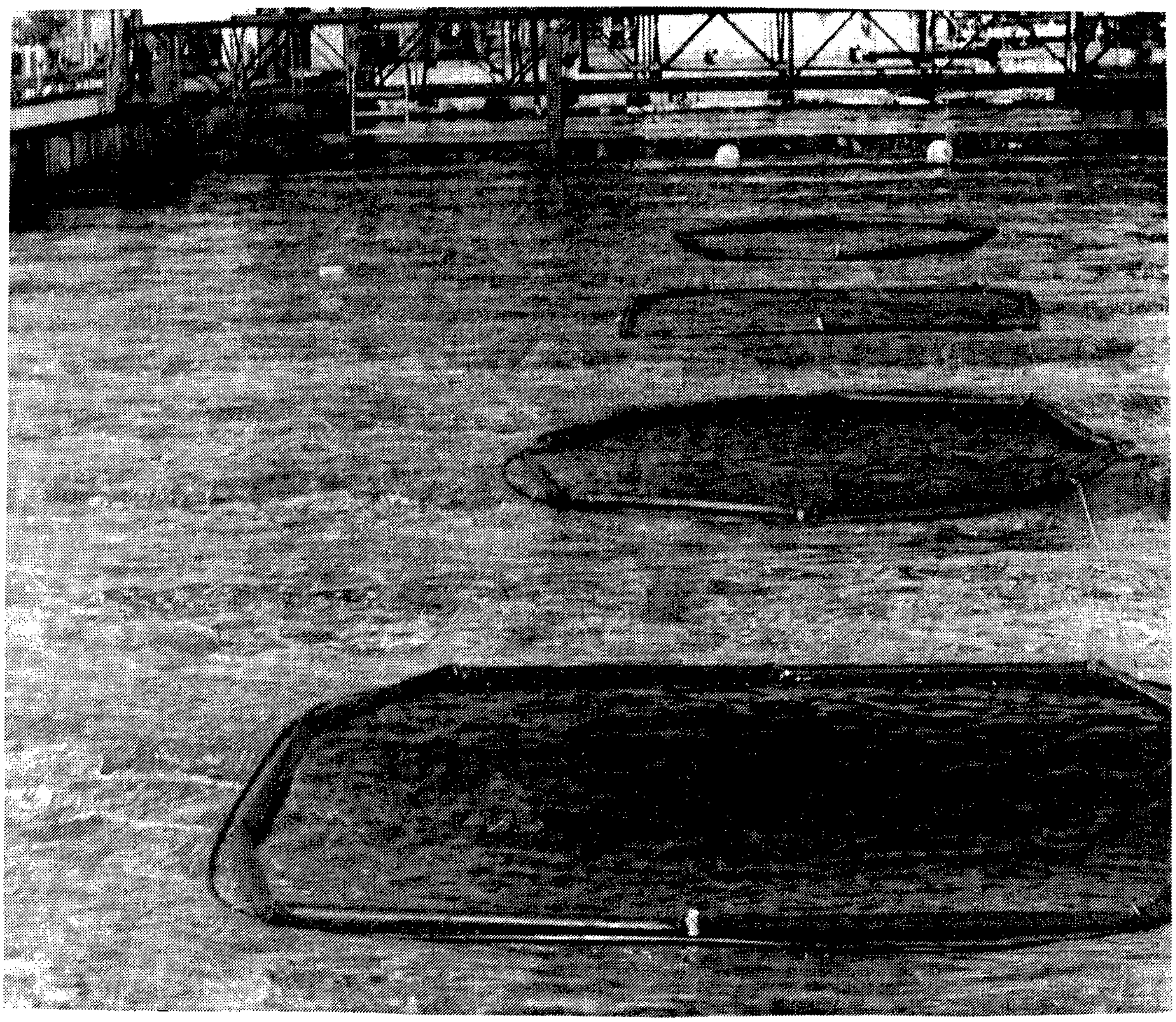

Figure 3-9 Photograph of Type 1 Oil Pools Under Medium Wave Conditions, Wave Condition 2

Figure 3-10 Photograph of Type 1 Oil Pools Under Harbor Chop 1 Conditions.

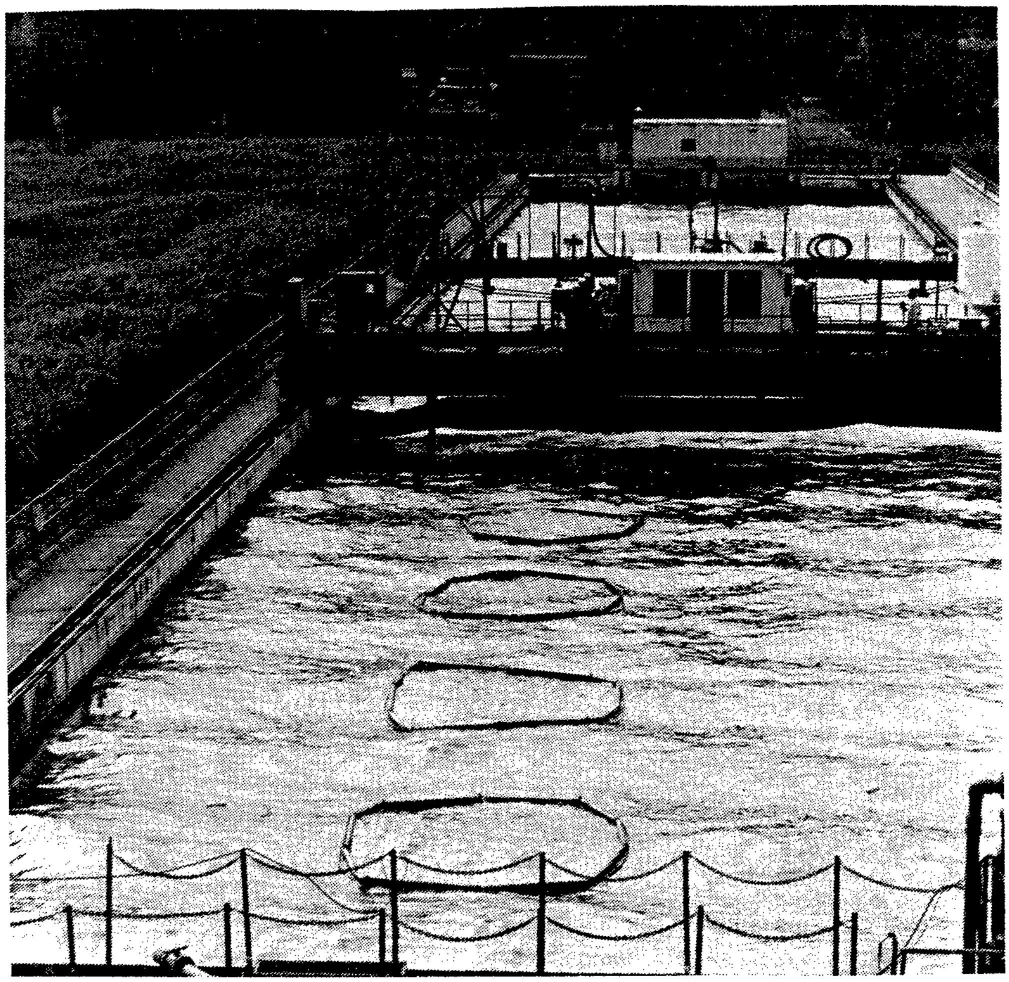

Figure 3-11 Photograph of Type 1 Oil Pools Under Harbor Chop 2 Conditions.

Figure 3-12 shows a close-up detail of the wave generator. The beaches can be seen under the water surface in Figure 3-13.

Table 3-1 is a test summary matrix which indicates the date each test was completed, the file identifier, and the number of FSR data files collected during that session for the specified wave conditions and oil parameters.

Figure 3-12 Photograph of the Wave Generator Flaps

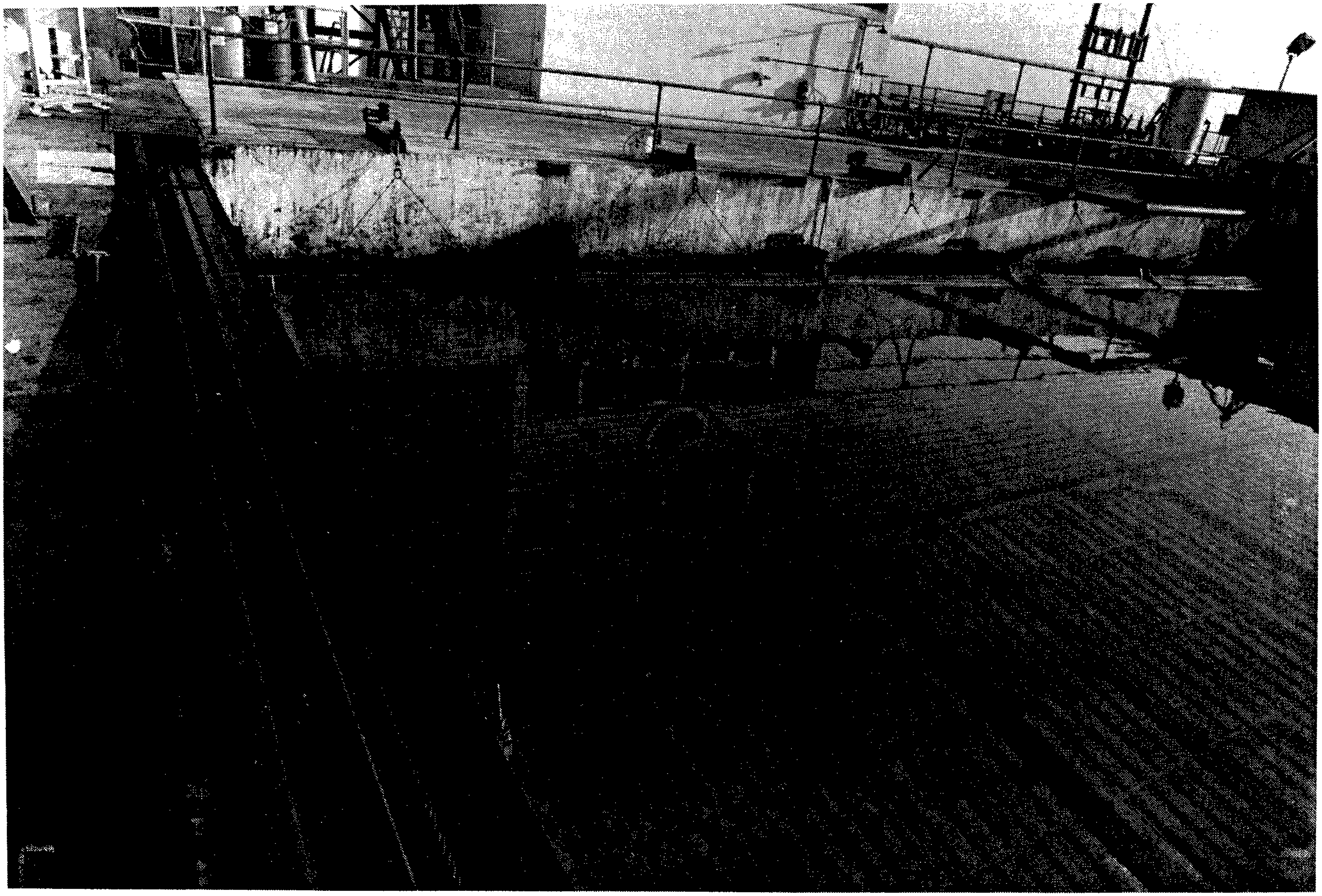

Figure 3-13 Photograph of the Beaches.

Table 3 - 1
Summary of Data Collected at OHMSETT During FSR Test

	Wave Conditions				
Oil Type and Thickness (mm)	Calm	Wave 1	Wave 2	Chop 1	Chop 2
	Date/ID/# Files	Date/ID/# Files	Date/ID/# Files	Date/ID/# Files	Date/ID/# Files
Type 1 - 0.0	13/U/3 14/H/4	13/V/4	13/W/3	14/I/3	14/J/4
0.5	13/U/3 14/H/8	13/V/3	13/W/6		
1.0	13/U/4 14/H/7	13/V/6	13/W/3		14/J/3
2.0	13/U/6 14/H/6	13/V/6	13/W/6	14/I/3	14/J/3
3.0	13/U/8 14/H/7	13/V/6	13/W/5	14/I/3	14/J/5
8.0	13/U/9 14/H/8	13/V/6	13/W/4	14/I/8	14/J/3
MOVING	14/FLY/3				
Type 2 - (Note 1)					
0.0	17/L/3 18/M/3	18/N/3	18/P/3		18/Q/3
2.5 @ 10%,	17/L/11 18/M/2	18/N/3	18/P/3		
2.5 @ 20%,	17/L/3 18/M/12	18/N/3	18/P/3		18/Q/3
2.5 @ 40%,	17/L/9 18/M/9	18/N/3	18/P/3		18/Q/3
2.5 @ 80%,	17/L/5 18/M/8	18/N/5	18/P/3		18/Q/5
2.5 @ 100%	17/L/3 18/M/11	18/N/5	18/P/3		18/Q/3
Lost Oil					18/Q/3

Note 1 - Type 2 oil conditions are expressed as the volume of Type 2 oil which would produce a thickness of 2.5 mm over the indicated percentage of the constrained area.

Table 3 - 1 (cont.)
Summary of Data Collected at OHMSETT During FSR Test

	Wave Conditions				
Oil Type and Thickness (mm)	Calm	Wave 1	Wave 2	Chop 1	Chop 2
Type 3 - (Note 2)					
0.0	14/EM/3				14/EW/4
0.5 @ 20%					14/EW/2
1.0 @ 20%	14/EM/5				
2.0 @ 20%	14/EM/5				
1.0 @ 40%	14/EM/5				14/EW/1
2.0 @ 40%	14/EM/5				14/EW/4
Lost Oil					14/EW/1
Unknown - 0.0	19/UNK/3	19/UNKW/3	19/UNKX/3	19/UNKY/3	19/UNKZ/3
Pool 1	19/UNK/7	19/UNKW/3	19/UNKX/3	19/UNKY/4	19/UNKZ/3
Pool 2	19/UNK/13	19/UNKW/3	19/UNKX/3	19/UNKY/4	19/UNKZ/3
Pool 3	19/UNK/7	19/UNKW/3	19/UNKX/3	19/UNKY/3	19/UNKZ/3
Pool 4	19/UNK/6	19/UNKW/5	19/UNKX/3	19/UNKY/5	19/UNKZ/3
Pool 5	19/UNK/6	19/UNKW/6	19/UNKX/3	19/UNKY/3	19/UNKZ/3
Moving	19/FLY/3				

Note 2 - Type 3 oil conditions are expressed as the target thickness of the Type 3 oil emulsion, and the percentage of water by volume in that emulsion.

3.4 ON-SITE EQUIPMENT CHECKOUT

The purpose of the on-site equipment checkout was to (1) verify that the FSR equipment was operating properly prior to installation on the OHMSETT bridge, (2) check the background noise level by pointing the antenna in the same direction as planned for the actual tests, (3) obtain a set of FSR signatures for the same oil type that was used during the actual tests.

The on-site equipment checkout consisted of measuring the expected Type 1 oil, RECCO 60, in the small, laboratory-fabricated test tank. Measurements were collected at oil thicknesses of 0.0, 0.5, 1.0, 2.0, 3.0, and 6.0 mm, and the results are shown in table 3-2. In the course of the equipment check-out and dry run tests, a decision was made to substitute dyed diesel oil for the RECCO 60 oil. Tests were performed using the 6.0 mm layer of RECCO 60 in the laboratory-fabricated test tank using the same red dye to verify that the red dye did not affect the FSR measurements. Figure 3-14 illustrates the on-site equipment checkout using the 6.0 mm thickness of dyed RECCO 60. Plots of the brightness temperature versus frequency measurements taken during the on-site checkout tests are shown in Appendix B. As expected, the FSR operation was verified, no interference was observed and the RECCO 60 measurements and the dyed RECCO 60 measurements (after an appropriate settling time to disperse trapped air and water) agree well with theoretical predictions.

3.5 OHMSETT DRY RUN

The purpose of the dry run day was to verify that (1) the FSR equipment could be mounted and operated on the OHMSETT bridge, (2) the oil target containment method was capable of keeping the oil contained during wave generation, (3) the patchy oil target coverage remained consistent over a test period.

The first day suitable for testing was 11 October 1994. Photographs of the FSR position on the main bridge are shown in figures 3-15, 3-16, and 3-17. The FSR equipment was mounted near the center of the equipment bridge, next to the

Table 3 - 2
Results of Visual Oil Thickness Analysis For FSR On-Site Tests

Actual Thickness (mm)	11 October 94			
	Pass 1 (mm)	Pass 2 (mm)	Pass 3 (mm)	
0.0	Reference	*		
0.5	0.475	0.425		
1.0	0.900	0.800		
2.0	2.075	1.900	1.950	
3.0	3.075	2.975		
6.0	5.875	5.925		
12 October 94				
	Pass 1 (mm)	Pass 2 (mm)	Pass 3 (mm)	Pass 4 (mm)
6.0 - No Dye	5.975	5.925	6.175	
6.0 - Red Dye	Inconclusive (Note 1)	Inconclusive (Note 1)	6.125	6.200

* A slightly elevated T^B was reported relative to pass 1 because the FSR amplifiers had not yet reached thermal equilibrium relative to the reference pass. An example of the effects on estimating thickness by using each water measurement as the reference are shown in a comparison in section 4.2.2.

Note 1: After the introduction of the red dye into the oil, many air and water bubbles were observed on the surface of the oil. The bubbles were allowed to settle out, and new measurements were recorded approximately 2 hours later (passes 3 and 4). The bubbles on the surface of the oil created a quite different T^B versus frequency signature from the expected results.

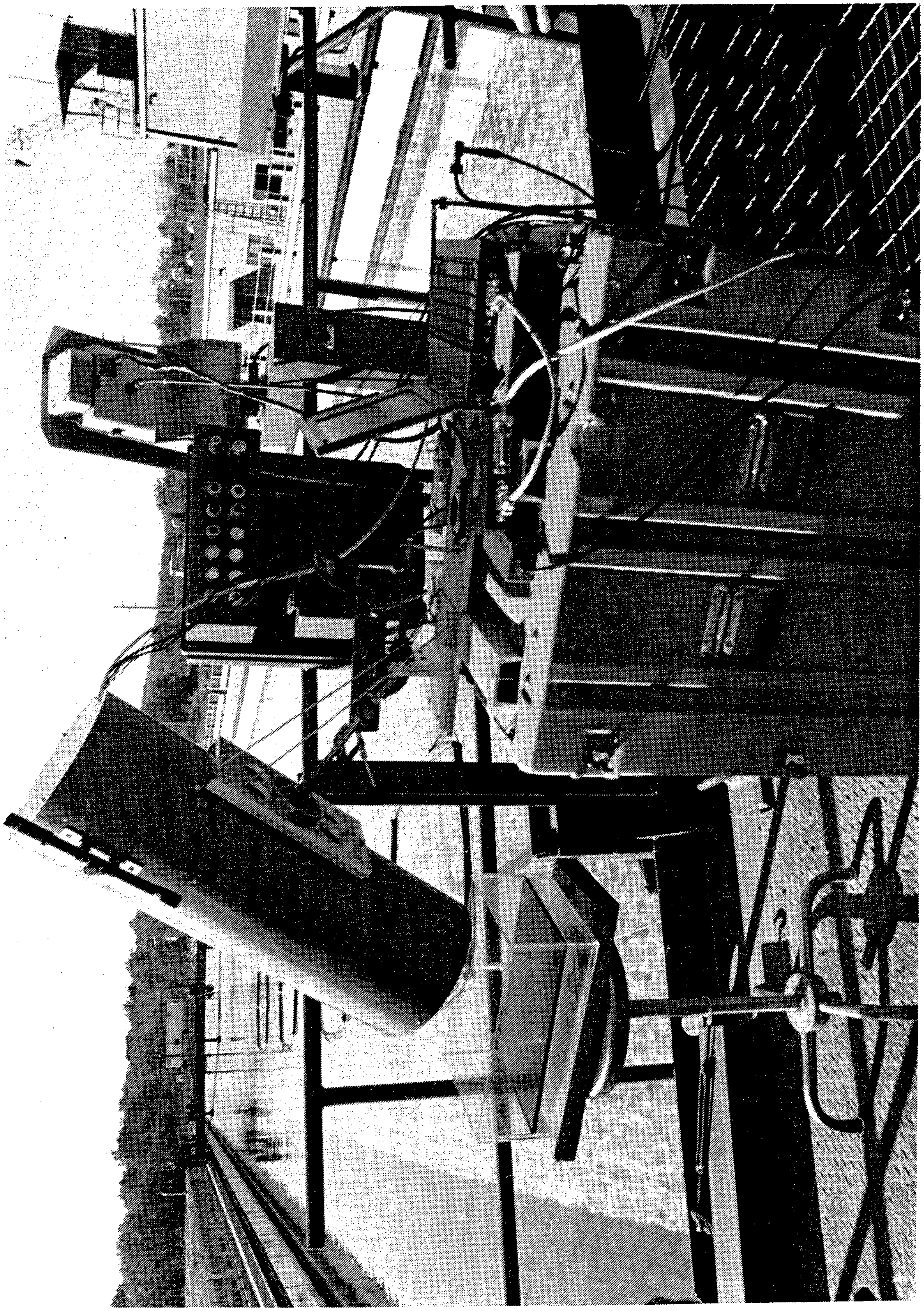

Figure 3-14 On-site equipment checkout

Figure 3-15 Photo of FSR on OHMSETT Main Bridge, Front View

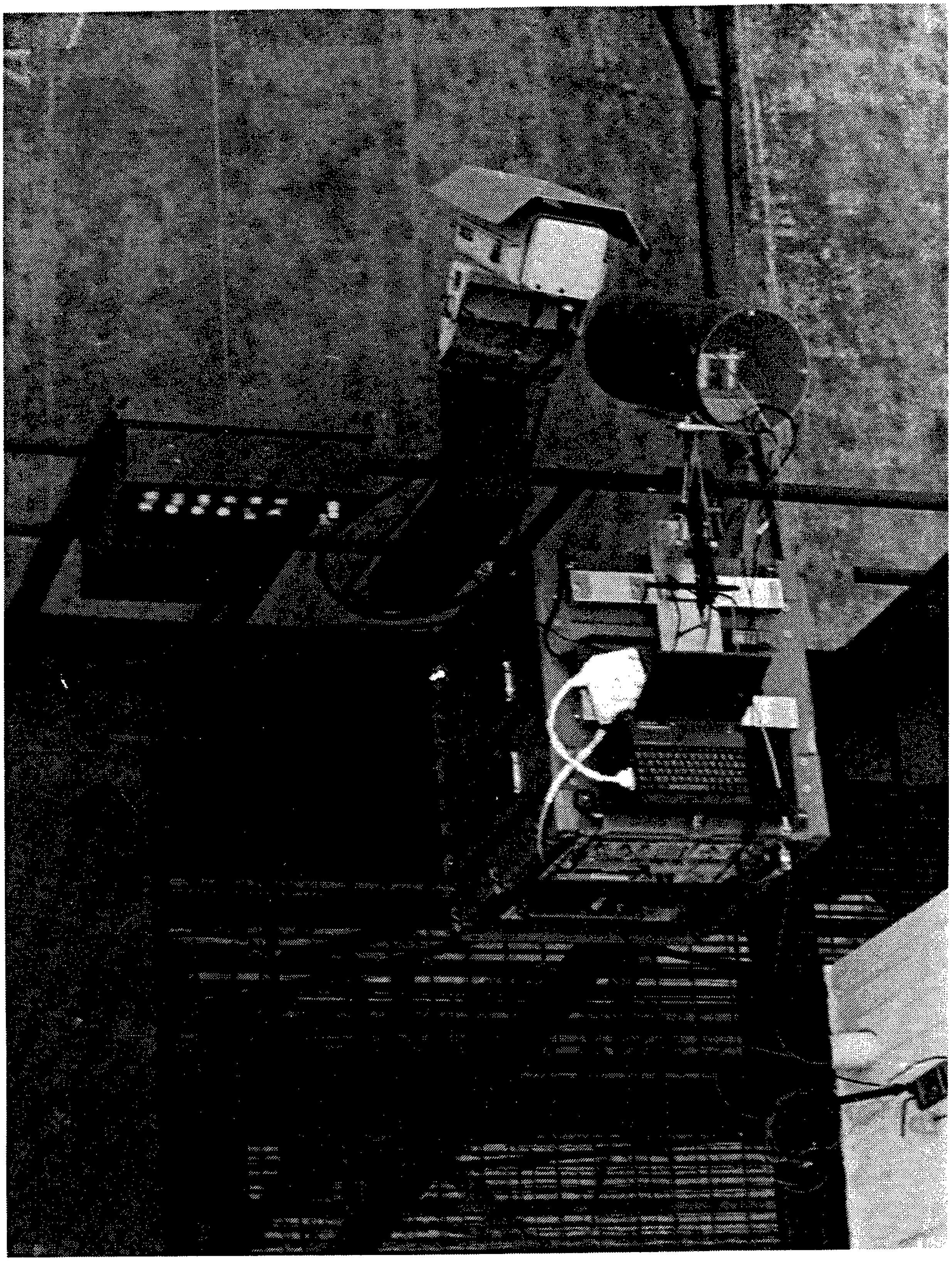

Figure 3-16 Photo of FSR on OHMSETT Main Bridge, Top View

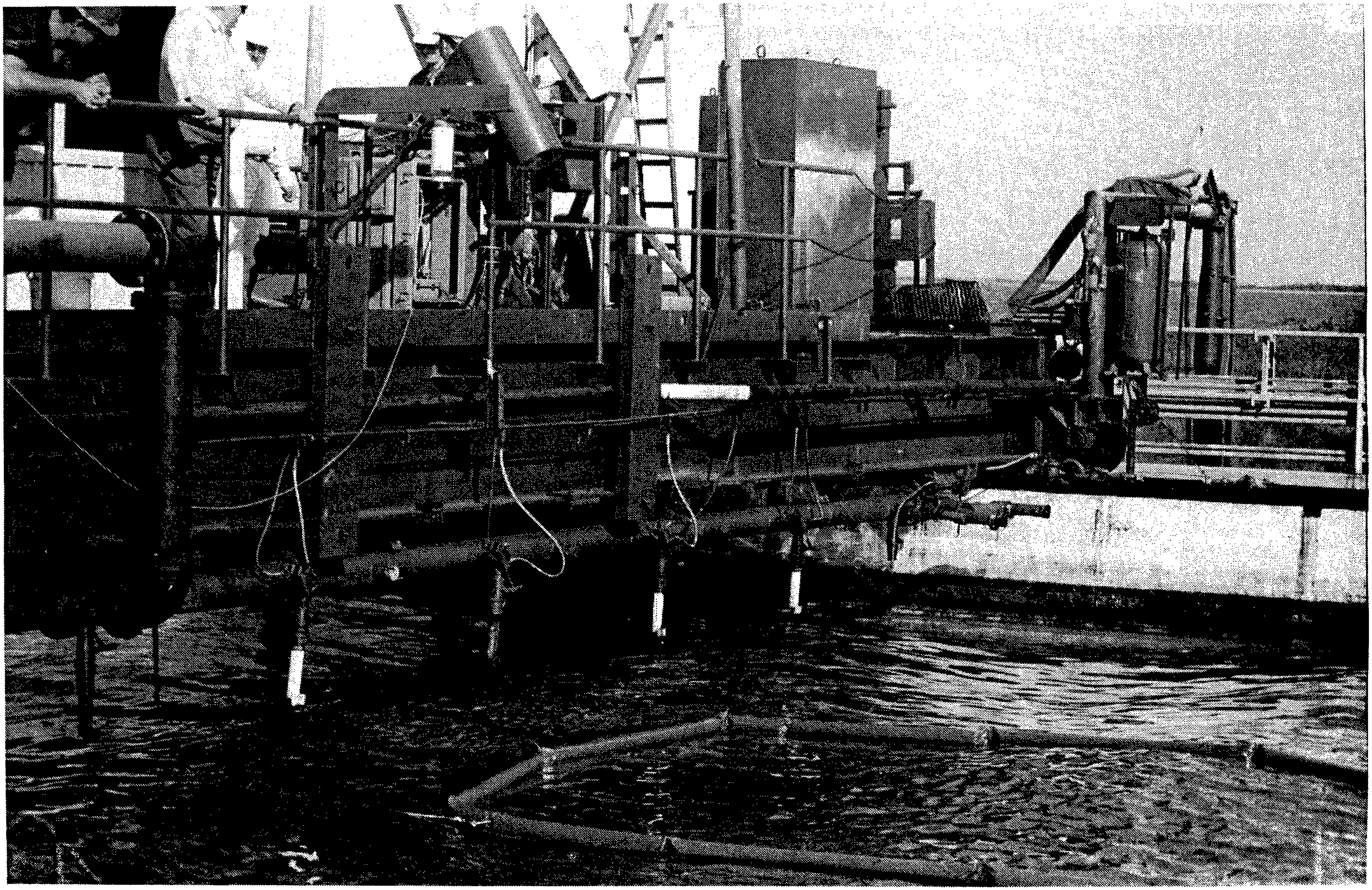

Figure 3-17 Photo of FSR on OHMSETT Main Bridge, View from Deck

enclosed shack, with the antenna approximately 10 feet above the surface of the water. The OHMSETT equipment bridge was moved up close to the test targets (oil pool areas) so that the FSR telescope could image the center of the constrained oil pools at a consistent depression angle of 60°, with the antenna configured to measure V-polarization energy over all the data collection runs. Prior to each data collection run, the radiometer was calibrated using the hot/cold load method (described in reference 1), and between collection runs the instrument was re-calibrated using the internally switched hot load termination.

An extensive dry run test was planned; however, the type 2 oil had not been delivered to OHMSETT (which precluded item (3) above), and the emulsion had not been mixed. For the purposes of dry-running the data collection procedures and obtaining initial oil signatures, one pool of RECCO 60 was spread in one of the containment pools. The RECCO 60 oil pool was spread by using an air driven pump to transfer the oil from a holding tank on the equipment bridge through a PVC pipe, shown in figure 3-18, to the oil pool. This method of oil dispersion created a layer of air and water bubbles entrapped on the oil surface. Initial FSR measurements showed consistently flat brightness temperatures usually associated with emulsions. The same oil target was measured at thicknesses from 0.0 mm to 5.0 mm incremented in 1.0 mm steps. This 5 mm oil pool was allowed to sit overnight during which time it settled into a homogeneous layer with no surface entrapments. Dry run testing continued on 12 October 1994.

Continuing with the dry run testing on 12 October 1994, the oil test targets consisted of a 5.0 mm thickness of RECCO 60, and one pool of dyed diesel. In order to avoid the air-entrapment problem encountered on the previous day, the diesel was spread by 5-gallon bucketfuls as shown in figure 3-19. Diesel oil thicknesses of 1.0 mm to 5.0 mm were measured in 1.0 mm increments, then an 8.0 mm thick diesel oil target was measured.

The test targets consisted of 15-foot diameter constrained oil pools, as shown in figure 3-19, and were located in the middle third of the tank, somewhat east of center. (The tank runs approximately north to south, with measurements made from the north side of the target pools, so the pools were somewhat left of center looking south.)

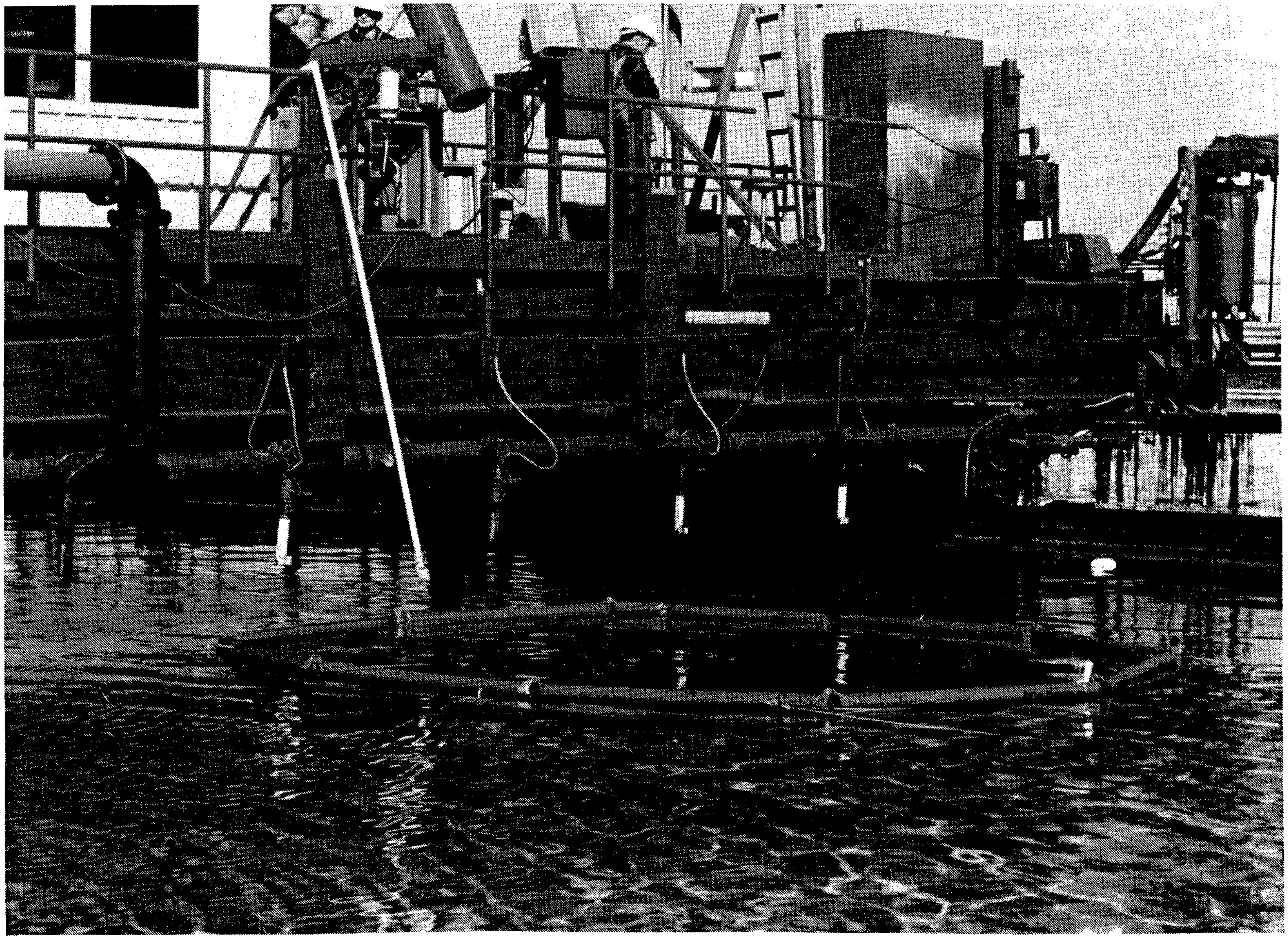

Figure 3-18 Photo of the Oil "Delivery" Apparatus

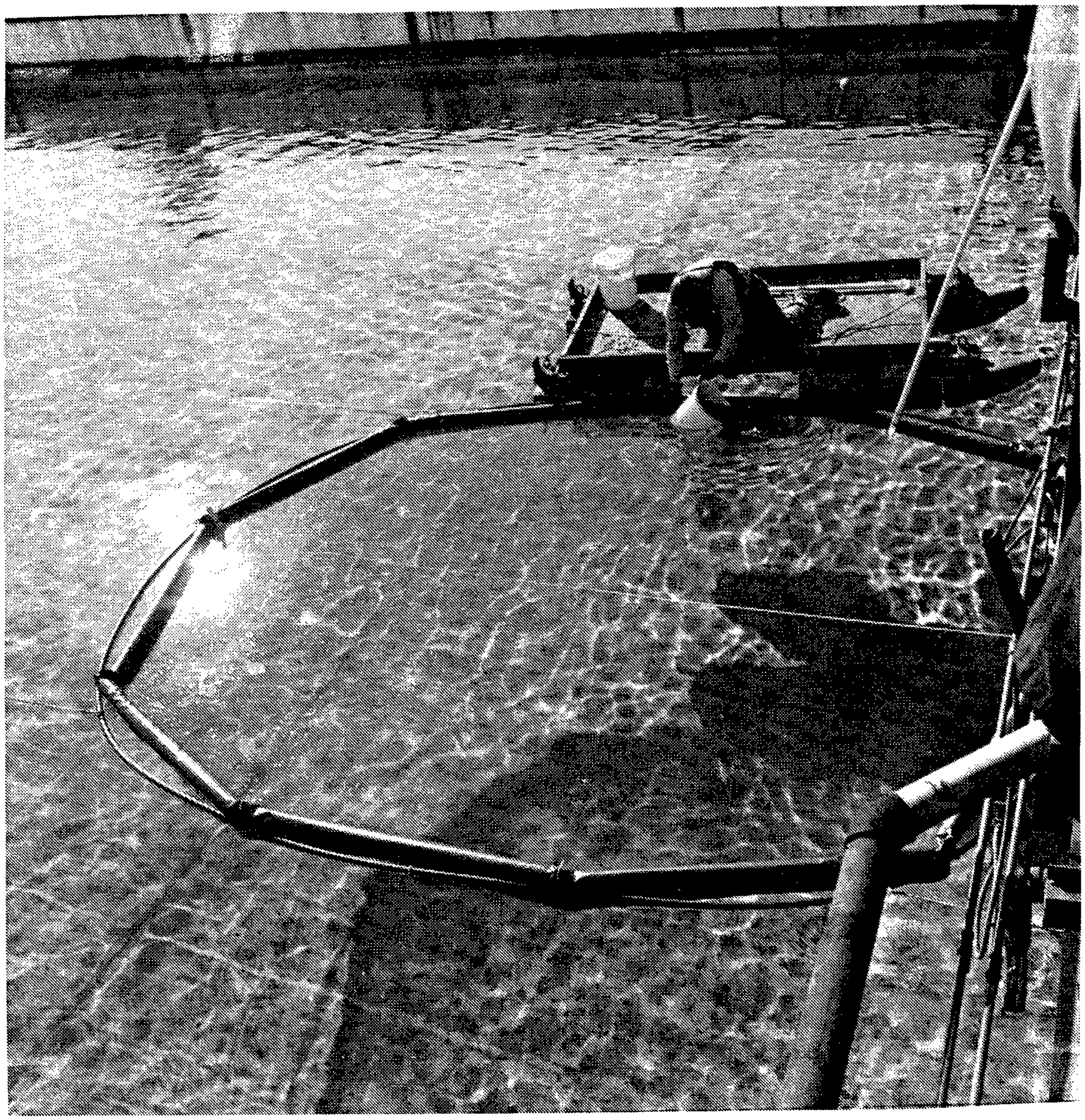

Figure 3-19 Photo of Alternate Method of Oil Delivery

Data runs were conducted under a number of different wave conditions with the 8.0 mm diesel oil target only. The wave conditions were calm, wave condition 1, and wave condition 2 waves as described in section 3.3. Because of time constraints, no harbor chop measurements were collected during the dry run day. During the course of this test, the wavelength and amplitudes of the waves generated in the wave tank were "fine tuned" by choosing the stroke and frequency of the wave generator so that little or no oil would be lost from the oil pools. Specific information identifying each collection pass was recorded on a form similar to figure 3-20.

At the conclusion of the dry run test, it was determined that the oil for the thin pools would be either gravity fed from the equipment bridge, or manually set-out using 5-gallon buckets to avoid the introduction of air and water bubbles in the oil surface. Dyed diesel oil was chosen to be the type 1 oil since it was known to be capable of producing uniformly thin oil layers, and was readily available. Modified wave conditions were selected so that the containment booms would keep the oil contained with minimal leakage. During the actual oil target tests, it was found that small quantities of oil would escape from the targets in the wave 2 condition, and that significant losses of oil were observed under the harbor chop 2 condition.

Plots of brightness temperature versus frequency of the data collected during the dry run days are shown in Appendix C.

3.6 GENERAL TEST PROCEDURES

At the start of each daily collection, the FSR was calibrated using the hot/cold load calibration procedure. Verification measurements were taken over clear water areas to ensure that the instrumentation was operating within normal parameters.

For each collection day, the FSR equipment was mounted near the center of the equipment boom, between the downlooking video camera and the wave height sensor. Using the boresighted marks on the FSR antenna telescope as a guide,

Date ______________________

Collection Day ______________________

Oil Type ______________________

Cloud Type/Percentage Cover ________/________

Ambient Temp/Water Temp ________/________

Backup Disk ID ______________

Antenna-to-Water Vertical Distance__________

FSR Operator ______________

Start Time	End Time	File Name	Oil Thick/ Type/ Coverage	Wave Height/ Length	Depr. Angle	Film #/ Frame #/ Video #	Comments

Figure 3-20 OHMSETT Data Collection Recording Form

the FSR operator passed positioning instructions to the OHMSETT bridge operator, directing bridge movements (north or south along the long axis of the pool) so that the intended portion of the test targets (oil pool areas) was imaged at a consistent depression angle of 60° ± 3° over all the data collection runs. Prior to the collection runs, and as necessary during the collection runs, the radiometer was calibrated using the hot/cold load method. OHMSETT surface truth data recordings (downlooking video and 10-Hz meteorological and wave data) were tagged with start and end markers that corresponded in time with the collection of FSR data.

Data runs were conducted using different oil types under a number of different wave conditions, namely, calm, wave condition 1 (small waves), wave condition 2 (medium waves), calm, harbor chop 1 and harbor chop 2. During some of the collections, the Coast Guard COTR and the Lincoln Laboratory Test Director agreed that data could be taken over a subset of these wave conditions. In all cases, during each run a minimum of two independent measurements were collected over each pool. As a "sanity" check, each measurement was compared, using the laptop screen plotting capability, to the FSR operator's best guess for the actual oil thickness in each pool. Specific information identifying each collection pass was recorded on a form similar to figure 3-20. Plots of brightness temperature versus frequency for all of the data collected at OHMSETT are contained in Appendices D through H.

3.7 UNIFORM THICKNESS MEASUREMENTS

The purpose of the uniform thickness measurements was to collect FSR brightness temperature signature data on five uniform thickness layers of Type 1 Oil under different wave conditions. The measurements were conducted on 13 and 14 October 1994. As planned, the oil test target set consisted of uniform thickness oil pools of 0.5 mm (2.44 gal), 1.0 mm (4.88 gal), 2.0 mm (9.77 gal), 3.0 mm (14.66 gal), 8.0 mm (39.1 gal) and a background pool with no oil. The test targets consisted of 3-meter diameter constrained pools which were located in the middle third of the tank, somewhat east of center, with the thinnest layers closest to the beach. The thinner oil layers were spread by hand using 5 gallon bucketfuls of oil; while the thicker layers were spread by gravity

feed from the oil storage container on the OHMSETT boom, and measured out (metered) as inches of oil from the tank. During this application of the oil in the pools, it was found that the volume of oil delivered could not be measured with great accuracy. The margin of error is assumed to be at least ±10%; in the case of the 2.0 mm uniform oil pool under calm conditions, the FSR consistently measured a thickness of 3.0 mm of oil. Data runs were conducted under all of the planned wave conditions; namely, calm, wave condition 1 (small waves), and wave condition 2 (medium waves) on 13 October 1994, and calm, harbor chop 1 and harbor chop 2 on 14 October 1994. Plots of brightness temperature versus frequency for the data collected during the uniform thickness measurements are shown in Appendix D.

During this data collection, the laptop computer "crashed" at the start of some of the runs. The problem causing the computer to crash appeared to be glitches on the HPIB interface, however, this was never verified. The HPIB cables and interface were wrapped with conducting foil, which in turn was grounded. This seemed to decrease the occurrence of crashes, however, it did not completely eliminate the problem. A result of this problem was the loss of approximately 10 data files collected over the 3.0 mm and 8.0 mm target pools on 13 October 1994. The loss of data occurred because the laptop DOS file naming convention only allows eight characters before the file type delimiter (.dat), and the window for naming the files had an 80 character line, so that some files were inadvertently overwritten when a double character strike caused the specific file delimiter (e.g., the a, b, c, etc. on file names such as u101380a.dat, u101380b.dat, u101380c.dat) to become the ninth character (e.g., u1011300a.dat). In this example, the ninth character would be truncated and all files (e.g., a through d) would overwrite the file u1011380.dat.

3.8 PATCHY OIL MEASUREMENTS

The purpose of patchy oil measurements was to collect FSR brightness temperature signature data on patchy oil layers filling four different percentages of antenna footprint, under various wave conditions. The oil test targets consisted of quantities of Type 2 Oil that were equivalent to a 2.5 mm oil thickness covering 10%, 20%, 40%, 80% and 100% (uniform layer) of the target

pool. These measurements were completed on 17 and 18 October 1994 using Alberta light sweet crude oil obtained from Imperial Oil of Canada. The volume of oil used for each of the oil targets was 1.22 gal, 2.44 gal, 4.88 gal, 9.76 gal, and 12.21 gal for the 10%, 20%, 40%, 80%, and 100% coverage areas respectively. These volumes were computed assuming that approximately 20 - 25% of the light aromatics in the oil would evaporate overnight. In the low volume oil pools (pool with less than 40% coverage), the oil tended to stay clumped together, usually in the vicinity of the containment booms. FSR measurements were completed using the highest beam fill factor that could be used without interference from the containment boom. The percent-beam-fill was estimated by the FSR operator and recorded in the collection log. During wave condition, only limited control could be exercised over the instantaneous beam fill, so for analysis purposes, each FSR measurement must be compared to the down-looking video for the actual conditions.

On 17 October 1994, after the oil pools had settled, an initial measurement pass was collected under calm conditions as a background measurement for the crude oil. It was expected that approximately 25% of the volume of oil would evaporate overnight. During the collection of 18 October 1994, data was again collected under calm conditions; however, after each uniform measurement in the pool was completed, an area within the oil target was mechanically stirred so that the oil could form clumps in the calm pools. Data was collected using the clumpy oil targets in the calm pools shown in figure 3-4. Data continued to be collected on 18 October under a number of different wave conditions, namely, wave condition 1(small waves), wave condition 2 (medium waves), and harbor chop 2. Plots of brightness temperature versus frequency for the data collected during the patchy thickness collection days are shown in Appendix E.

3.9 EMULSIONS

The purpose of emulsion measurement was to collect FSR brightness temperature signature data on uniform thicknesses of emulsified oil using Type 3 Oil, under different wave conditions. Water/oil emulsions containing 20% and 40% water by volume were mixed by OHMSETT personnel. The data collection plan called for test targets consisting of 1.0 mm, 2.0 mm, and 4.0 mm layers of

the 20% mixture, 2.0 mm and 4.0 mm layers of the 40% mixture, and a background water pool set up in the 3-meter diameter constrained oil pools. However, when the oil was set out it tended to clump together and remain near the edges of the containment booms.

Because the emulsified oil in the pools remained clumped together, and previous laboratory FSR results showed little to no ability to quantitatively measure the emulsion thickness, data runs were conducted using only two different wave conditions. The wave conditions were calm and harbor chop 2. An attempt was made to achieve different beam fill ratios in different data files. The FSR operator would position the antenna beam over an oil clump area, and estimate the percent of oil in the beam to the nearest 10%. This percent-beam-fill information was recorded in the equipment operation log. Plots of brightness temperature versus frequency for the data collected during the emulsion thickness collection days are shown in Appendix F.

3.10 UNKNOWN THICKNESS MEASUREMENTS

The purpose of test day 4 was chosen to be measurements of FSR signatures on a set of unknown oil thicknesses. The selection of the test day 4 oil type and film thicknesses was made by the USCG R&D Center COTR and the OHMSETT facility manager. The test targets consisted of five unknown oil films and one background water pool, each configured as a 3 meter diameter constrained pool, with these pools located in the middle third of the tank.

Plots of brightness temperature versus frequency for the data collected during the unknown thickness collection days are shown in Appendix G.

3.11 FLYING (MOVING BRIDGE) MEASUREMENTS

On two separate occasions, oil film thickness measurements were completed with the equipment bridge traveling (moving) over the oil pool as FSR data was being collected. The idea behind the flying measurements was to create a 'small-scale flight simulator' to determine whether there were any unique data

anomalies that could be tied to antenna movement. One set of measurements was completed on 14 October using Type 1 oil, and the second set was completed on 19 October during the day 4 unknown thickness collection. Both sets of measurements were completed under calm conditions.

Plots of brightness temperature versus frequency for the data collected during the "flying" measurements are shown in Appendix H.

3.12 SURFACE TRUTH INFORMATION

Surface truth information was collected by the OHMSETT facility staff. The information included the following data sets annotated with date, time, and run identifier. Each file contains marker points that correlate with the start and end of an FSR data collection sweep. Surface truth information was collected at a 10 Hz rate and contained the following items.

1. Meteorological Data - Two sets of wind speed and direction were recorded (1) within 1 foot of the tank's surface, and (2) approximately 10 feet above the deck. Cloud cover, air temperature, and water temperature were also recorded during periods when the FSR was collecting data. Water salinity was reported and did not change significantly over the period of the experiment.

2. Wave Data - Wave measurements were taken using an above-water sonic probe that measured the distance from its mounting to the water surface. The frequency of the wave generator was also measured.

3. Bridge Position Data - Bridge position data relative to a fixed point was recorded during periods when the FSR was collecting data.

4. Oil Data - A log of oil type and quantity, including known flow characteristics (e.g., viscosity, pour point) introduced into each enclosure was maintained for each oil target change. For emulsions, the percent water in oil by volume was also recorded.

Color videotapes were taken depicting the appearance of the appropriate oil target simultaneous with each FSR measurement using the downlooking video system on the OHMSETT equipment bridge. These videos contain a mark tone that delineates the start and stop times of FSR data collections. Still photographs and slides of the oil pools were shot by MIT/LL and USCG personnel involved with the experiment. Videotape coverage of actual equipment operation was provided by OHMSETT and USCG personnel.

CHAPTER 4

RESULTS OF FSR MEASUREMENTS COLLECTED AT OHMSETT

This chapter describes the results of the FSR measurements collected at OHMSETT. Section 4.1 details the data analysis algorithm used to compare each FSR data file with a family of theoretical T^B versus frequency curves and generate an estimated oil thickness. This method was used to compare and plot all of the data collected as part of the OHMSETT experiment. Sections 4.2, 4.3, and 4.4 will discuss the results of visual FSR data analyses and compare these to algorithm-generated estimates for the various oil types under calm, wave, and chop conditions, respectively. Section 4.5 will discuss the results of the emulsion measurements. Section 4.6 will discuss the results of measurements taken while the OHMSETT main bridge was moving, simulating a "flight" above the oil target pools.

4.1 DESCRIPTION OF OIL THICKNESS ESTIMATION ALGORITHM

During early proof-of-concept testing (described in reference 1), oil film thickness was determined by manually (visually) comparing FSR measurement plots of T^B versus frequency against a family of predicted (theoretical) curves which corresponded to selected oil thickness values. This family of curves consisted of theoretical predictions of oil brightness temperatures versus frequency for oil thicknesses from 0.0 mm to 10.0 mm in 0.025 mm steps. This family of curves was generated after first finding the best fit water brightness temperature curve for the measurement conditions. This water brightness temperature curve represented the ambient scene background temperature. Using this water background temperature data, and the known values of (1) typical dielectric constants for oil, water, and air, and, (2) the frequency band over which the FSR operates, the reflection coefficients of the air/oil/water

interfaces were computed. These reflection coefficients were then used to compute the theoretical radiometric brightness temperature curves.

The manual comparison of theoretical and FSR measurements for the large data set (approximately 800 files) collected at OHMSETT would be quite cumbersome and time consuming. A trained FSR operator can visually distinguish oil thicknesses to approximately 0.5 mm but because of the observed thickness variability of the oil targets, this estimate, although good enough for on-site verification, did not seem good enough for a final analysis. Based on these reasons, an oil thickness estimation algorithm was developed. A block diagram of the automated analysis process is shown in figure 4-1, and is described below.

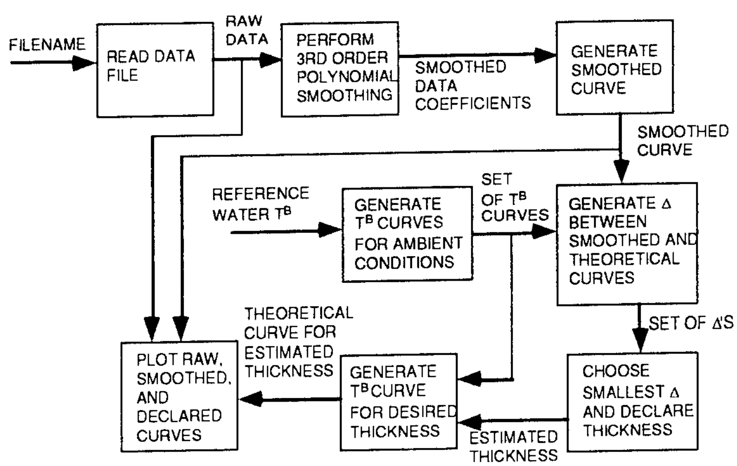

Figure 4-1 Block Diagram of Oil Thickness Estimation Process

A set of theoretical T^B curves for water using a range of 100° of expected ambient temperature condition variation is computed in 1°K steps over the Ka-band in frequency steps of 0.5 GHz. These theoretical T^B curves for water are compared to the FSR measurements obtained from the water background pool. The theoretical T^B curve with the least mean square error from the FSR

measurement is declared as the background water reference. Using that set of ambient conditions matching the selected background water reference, a set of oil-on-water T^B curves is computed in frequency steps of 0.5 GHz for oil thicknesses ranging from 0.000 mm to 10.000 mm in 0.025 mm steps. The small thickness step size is not meant to imply that the FSR can measure to this accuracy; it only creates a larger set of theoretical curves for comparison purposes.

The FSR measurement data file consists of a header which identifies the date, time and measurement type, the number of data samples (typically 16), and the measured T^B and frequency for each sample. The set of data samples spans the 26 to 40 GHz FSR frequency band. After the file is read, the measured data is smoothed using a third order polynomial curve-fitting routine. The coefficients of the third order polynomial are then used to regenerate a smoothed curve with a sample spacing of 0.5 GHz, which matches the sample spacing of the theoretical data set. This smoothed curve is compared to each of the theoretical curves on a point-by-point basis.

The smoothed measurement curve is compared to the reference set using a variety of methods, namely, (1) a least mean squares comparison, (2) correlation, and (3) comparison of the mean and slope of the curve (used to generate estimates of up to 4.0 mm oil thicknesses). The following paragraphs will describe each comparison technique.

Least Mean Squares (LMS). The 0.5-GHz-spaced point-by-point differences between measured and theoretical brightness temperatures are squared then summed, thereby giving a metric of how well the smoothed curve and the theoretical curve matched. The theoretical curve with the minimum least square difference is declared to be the best match. This method provides a good sense of the absolute value of differences between the measured FSR data and theoretical expectations, but is not sensitive to curve shape.

Correlation. The 0.5-GHz-spaced smoothed brightness temperature curve is correlated with each theoretical curve. Correlation is a numerical measure of the amount of association or closeness in the relation between two data sets (reference 3). The theoretical curve with the highest correlation coefficient is declared to be the best match. This method is used to find the curve that has the best shape match, but, unlike LMS, it is not sensitive to a constant offset between the two data sets.

Mean/Slope. For thicknesses up to about 4.0 mm, the T^B versus frequency response of oil approximates a straight line, with the most notable differences being the mean and slope of the curve. Arguably, this method is somewhat similar to the least mean square method described above, however, it is a much quicker computation, uses a different method to compare the curves (LMS doesn't consider slope directly) and serves to verify the LMS result. In the estimate tables presented in this report, one will find that the mean/slope method generates an output result even though the known input oil thickness is clearly greater than 4.0 mm. In any future operational system, it must assumed that the thickness of the oil being observed is unknown, and the observed data would therefore be presented to this part (or a similar part) of the oil thickness estimation algorithm. Thus, in this analysis, even though the mean/slope estimates are clearly unusable above the 4 mm thickness, the test was still performed and the results tabulated.

For each smoothed measurement curve, the slope between end points as well as the mean value of the curve is computed. These values are then compared via square differences to the slope and mean of each theoretical curve. The theoretical curve with the least square difference is declared to be the best match.

Thickness Declaration. From this set of three metrics (LMS declared thickness, correlation declared thickness, and mean/slope declared thickness), the smallest absolute difference between all combinations of these three thickness values is computed (i.e., |LMS - correlation|, |LMS - mean/slope|, |correlation - mean/slope|). If this difference value is less than or equal to 0.2 mm it is used to declare the estimated oil thickness. If the smallest difference is greater than 0.2 mm, the algorithm defaults to the least-mean-squares value (which seemed to provide the best single-method thickness estimation performance during this analysis). The original data set, smoothed curve, and estimated theoretical curve are then plotted and annotated with filename and estimated thickness. The analyst can choose to override the algorithm result and choose an estimated oil thickness curve that might be a better match to the measured data based on a visual analysis of the data. This algorithm was applied to every data set collected at OHMSETT to produce the curves shown in the Appendices. Comparisons and analyses in the remaining sections of this chapter will be based on the results of this oil thickness estimation algorithm.

In cases where the algorithm estimate did not fit the measured data well, manual intervention was used to select a better estimate. In cases where the oil target only partially filled the antenna beam, the analyst could choose a single estimated thickness and an estimated percentage of antenna beam fill to compute the theoretical T^B response. The partial beam fill concept was introduced in the analysis of non-uniform thickness measurements described in reference 4. The T^B prediction is produced by using the estimated percentage as a weighting factor (w, where $w \leq 1.0$) that is applied to the theoretical T^B response for that oil thickness; added to this is the weighted (1 - w) theoretical T^B response of background water.

Arguably, the comparison methods described above are not independent, and may not represent the best set of metrics for comparison. The algorithm was

developed to assist in the analysis of the OHMSETT data. The oil thickness estimation algorithm was optimized to give the best results on the data collected at Lincoln Laboratory on 5 and 6 October 1994, then applied to the data collected at OHMSETT later in October. The algorithm needs more development and testing before being used in an operational system. This investigation was to determine the usefulness of using an oil thickness estimation algorithm to analyze a large data set. This algorithm needs more development, for example, to take into account partial antenna beam fill effects.

The tables in this section show the results of each of the three methods used to derive the algorithm-based estimate. The table matrix cells that are gray indicate where there is a significant difference between any single method's result and the selected algorithm output. In a few cases where the visual analysis yielded inconclusive results, the plotted T^B versus frequency curve may not match the algorithm estimate. In these cases, there is a discussion in the relevant appendix of why that particular curve was chosen. The actual plotted results (T^B versus frequency) of each comparison are shown in the Appendices. Appendix A contains results from the Laboratory validation measurements. Appendix B contains the results of the OHMSETT on-site measurements using the laboratory-fabricated test tank. Appendix C contains the results of the dry-run measurements. Appendix D contains the results of the dyed diesel measurements. Appendix E contains the results of the crude oil measurements. Appendix F contains the results of the emulsions measurements. Appendix G contains the results of the unknown oil type and thickness measurements. Appendix H contains the results of the "flying" measurements.

4.2 CALM CONDITION MEASUREMENTS

Measurements of oil on water, under calm wave conditions, were collected on 11 and 12 October 1994 as part of the dry run; on 13 and 14 October using dyed diesel oil; on 17 and 18 October using crude oil; and on 19 October as part of the "unknowns" or blind collection. Some of the early measurements, particularly those from the dry run, show disappointing results; however, the measurements from the 13 and 14 October dyed diesel test and the unknowns test indicate that the FSR is capable of measuring oil thickness under calm conditions. The measurements using crude oil indicate that oil films that provide only partial antenna beam fill diminish the ability to correctly identify oil thickness using the automated algorithm. A priori knowledge of the approximate beam fill allows the analyst to manually experiment with oil thickness and percentage fill in order to get the best fit curve. One must be careful when using the partial fill method because the resulting T^B curves from low percentage beam fill estimates look very much like a full beam response from a thin (approximately 0.4 mm) oil.

Breaking up the oil into areas of patchy oil also created problems with the FSR's ability to estimate oil thickness. This is a combination of partial antenna beam fill effects, and the possibility of creating a low percentage water emulsion during the breaking-up of the oil surface.

4.2.1 Analysis of 11 October Measurements

Sixteen data files were collected using the OHMSETT oil targets during the dry-run on 11 October. This was the first time that the FSR collected data using a large-scale oil target. Each of the T^B versus frequency plots is shown in Appendix C with comments describing the fit of the algorithm estimate and ultimate choice of estimated thickness.

The initial water background measurement shows a false indication of oil. Review of the photos and videotape verified that there was no visible contamination of the water surface. While it is understood that the FSR is not capable of actually measuring oil this thin (0.025 mm), the oil estimation algorithm attempts to generate a best fit over a data set. Small noise variations, or in this case possible warm-up effects may have caused the water measurement to have a slightly higher T^B which would have caused the algorithm to falsely identify this as oil.

During this first day of testing, the results were somewhat disappointing; (1) there are many measurements below 4.0 mm of oil thickness where the resulting estimate is inconclusive, and (2) the algorithm results for almost all of the oil films measured show a poor correlation to the actual (intended) oil thickness. These two observations are probably related to the fact that during the dry run, air and water bubbles were seen on surface of the oil-on-water layer. It is believed that these bubbles caused the resulting measurement to appear "flat", with less peak-to-valley amplitude variation than expected for thicker oil targets and a near zero slope for thinner oil targets.

Table 4-1 documents the results of each of the methods used by the oil thickness estimation algorithm with the data collected on 11 October 1994. As noted above, for oil thicknesses less than 4.0 mm, the measured oil T^B response was quite flat and did not seem to match the theoretical predictions well. For oil thicknesses of 4.0 mm and greater, the characteristic shapes of the curves could be matched to a theoretical prediction, and that prediction/estimate usually compared favorably with the intended oil thickness for the measurement. Thus, the correlation-only results for thicknesses of 4.0 mm and above showed the closest agreement with the reported oil thicknesses.

Table 4-1. Results of 11 October 1994 Measurements

File Name	Reported Thickness (mm)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
B101100A	0.0	0.000	0.525	0.050	0.025	0.025
B101100B	0.0					Reference
B101110A	1.0	0.725	1.375	0.725	0.725	0.725
B101120A	2.0	0.975	3.875	1.000	0.975	Inconclusive
B101130A	3.0	0.825	4.125	0.850	0.825	Inconclusive
B101130B	3.0	1.050	7.200	2.350	1.050	Inconclusive
B101140A	4.0	1.775	1.800	1.400	1.775	5.000
B101140B	4.0	2.425	6.275	2.400	2.400	6.200
B101140C	4.0	0.950	3.475	0.950	0.950	3.40 - 3.60
B101140D	4.0	1.150	7.400	1.150	1.150	3.8 or 7.4
B101150A	5.0	2.500	6.350	2.475	2.475	6.300
B101150B	5.0	2.400	5.975	2.375	2.375	6.000
B101150C	5.0	5.675	5.825	2.350	5.750	5.750
B101150D	5.0	2.425	6.350	2.400	2.400	6.350

4.2.2 Analysis of 12 October Measurements

The following data set was collected on 12 October, using the 5 mm RECCO 60 oil target deployed on 11 October, after it had settled overnight. The 'C' measurements were collected over water with no oil film, followed by the 'D' measurements that were collected over the RECCO 60 oil target; these measurements comprise a total of eleven data sets. Seventeen 'E' measurement sets were also collected on 12 October, using dyed diesel oil targets of different thicknesses. The T^B versus frequency plots for these data sets are contained in Appendix C.

Table 4-2a documents the results of the 12 October 1994 RECCO 60 oil measurements for each of the methods used by the thickness estimation algorithm. The results for the water-only pools again indicate that small variations in the water-only measurement can lead to false positive identification of a very thin oil film. To investigate the effect of using the most recent water background measurement on the algorithm results, the water reference was switched to the C101200C data file. Table 4-2b documents the results of this investigation. The algorithm output results still do not match the reported oil target thickness; however, with the exception of the D10125A entry, all of the algorithm results are within one sample (0.025 mm thickness) of the results shown in table 4-2a. As expected, the small change in water background reference did not significantly change the results of the thickness estimations. Perhaps, as part of a final system, averaging the measurements should be considered to reduce the effects of small noise and electronic drift effects.

Overall, the declared output of the oil thickness estimation algorithm showed disappointing results; however, the correlation-only estimates had the best match to the visual analysis results. In most cases, the correlation only estimate was a good match to the raw data curve shape, which also showed good agreement with the reported oil target pool thickness. However, amplitudes were damped relative to the expected measurement curves.

Table 4-3 documents the results of the 12 October 1994 dyed diesel oil measurements for each of the methods used by the thickness estimation algorithm. The results shown in the table indicate that for intended oil thicknesses of 4.0 mm and greater, the algorithm estimates agree with the visual analysis of the T^B versus frequency curves. At intended thicknesses of 3.0 mm and below, most of the algorithm estimates agree with the intended oil film thickness, though the visual comparisons of the measured T^B versus

Table 4-2a. Results of 12 October 1994 Dry-Run Measurements of RECCO 60 oil Under Calm Conditions.

File Name	Reported Thickness * (mm/% cov.)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
C101200A	0.0					Reference
C101200B	0.0	0.150	4.400	0.175	0.150	Warm-up
C101200C	0.0	0.075	4.425	0.075	0.075	Warm-up
D101250A	5.0/100%	8.625	1.800	0.750	8.625	5.200
D101250B	5.0/100%	0.675	1.800	0.700	0.675	5.100
D101250C	5.0/100%	0.000	7.125	0.000	0.000	Inconclusive
D101250D	5.0/100%	3.850	4.350	0.600	3.850	4.00 - 4.40
D101250E	5.0/100%	0.750	5.050	0.750	0.750	5.000
D101250F	5.0/100%	2.775	5.975	2.825	2.800	5.900
D101250G	5.0/100%	3.125	3.200	3.025	3.150	3.15 or 6.65
D101250H	5.0/100%	3.225	3.250	3.150	3.225	3.225 or 6.7

Table 4-2b. Results of 12 October 1994 Dry-Run Measurements of RECCO 60 Oil Using a Different Reference Under Calm Conditions

File Name	Reported Thickness * (mm/% cov.)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
C101200A	0.0	0.000	4.450	0.000	0.000	0.000
C101200B	0.0	0.125	4.400	0.125	0.125	0.125
C101200C	0.0					Reference
D101250A	5.0/100%	0.725	1.800	0.750	0.725	5.200
D101250B	5.0/100%	0.675	1.800	0.675	0.675	5.100
D101250C	5.0/100%	0.000	7.125	0.000	0.000	Inconclusive

Table 4-2b. Results of 12 October 1994 Dry-Run Measurements of RECCO 60 oil Using a Different Reference Under Calm Conditions (cont.)

File Name	Reported Thickness * (mm/% cov.)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
D101250D	5.0/100%	3.850	4.350	0.575	3.850	4.00 - 4.40
D101250E	5.0/100%	0.750	5.050	0.750	0.750	5.000
D101250F	5.0/100%	2.800	5.975	2.825	2.800	5.900
D101250G	5.0/100%	3.125	3.200	3.025	3.150	3.15 or 6.65
D101250H	5.0/100%	3.225	3.250	3.175	3.225	3.225 or 6.7

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

frequency curves with the theoretical predictions show inconclusive results, except for E101230A. The measured data, algorithm estimate and final curve fit all match well.

It is not understood why the diesel results seem better than the RECCO 60 results. Clearly, the expected sinusoidal variation of T^B is present, but seems damped in the RECCO 60 oil. Perhaps the refined RECCO 60 product has a higher absorption or attenuation coefficient than the diesel oil, lowering its emission properties in this frequency band.

Table 4-3. Results of 12 October 1994 Dry-Run Measurements of Dyed Diesel Oil Under Calm Conditions

File Name	Reported Thickness * (mm/% cov.)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
E101200A	0.0					Reference
E101200B	0.0	0.000	4.425	0.000	0.000	0.000
E101210A	2.5/40%	0.900	4.775	0.900	0.900	Inconclusive
E101210B	2.5/40%	0.950	4.925	0.950	0.950	Inconclusive
E101210C	2.5/40%	2.575	2.200	2.600	2.575	Inconclusive
E101220B	4.0/50%	2.775	2.750	2.725	2.750	Inconclusive
E101230A	5.0/60%	3.275	3.325	3.125	3.300	3.300
E101230B	5.0/60%	2.775	2.850	2.725	2.750	Inconclusive
E101230C	5.0/60%	3.175	3.275	2.950	3.225	3.225
E101240A	4.2/90% - 95%	3.800	3.925	3.775	3.800	3.800
E101240B	4.2/90% - 95%	3.850	3.975	3.825	3.850	3.850
E101240C	4.2/90% - 95%	3.950	3.950	3.975	3.950	3.950
E101250A	5.0/100%	4.550	4.650	0.925	4.600	4.600
E101250B	5.0/100%	5.025	1.800	0.925	5.025	5.025
E101250C	5.0/100%	8.225	4.950	0.950	8.225	8.225 or 5.0
E101280A	8.0/100%	8.200	8.175	2.800	8.175	8.175
E101280B	8.0/100%	7.875	7.875	2.650	7.875	7.875

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

4.2.3 Analysis of 13 October Measurements

The measurements collected on 13 October were made using Type 1 (dyed diesel) oil. Table 4-4 documents the results of these measurements for each of the methods used by the thickness estimation algorithm. The T^B versus frequency curves for this data set are contained in Appendix D. The algorithm output, in all cases other than the target pool with the intended thickness of 1.0 mm, agrees with the visual analysis of the FSR data. In turn, the visual analysis seems to agree reasonably well with the reported thickness of the oil target pools.

The 1.0 mm (intended) thickness plots (U101310A - D) seem to have a lower T^B amplitude versus frequency than is predicted by the theoretical models, and the visual analysis estimates from these curves are based primarily on the shape of the curve. Based on the OHMSETT reported oil thicknesses, these estimates do fall within a thickness range consistent with reported values. Figure 4-2 is a photograph of the 1.0 mm (intended thickness) oil target pool; this picture was taken during the first measurement sweep. The photo, the site notes, and the OHMSETT video do not indicate any abnormalities with this oil target other than the oil film at the north end appearing to be thicker than the oil film at the south end. Figure 4-2 shows a darker appearance in the oil target near the bottom (north end) compared to the top. Two measurements were made at the north end (U101310A, B) with the second two measurements at the south end (U101310C, D). As shown in table 4-4, both the algorithm and the visual analyses of these T^B versus frequency curves tends to support the hypothesis of an oil wedge within the pool, but not conclusively.

Table 4-4. Results of 13 October 1994 Measurements of Dyed Diesel Oil Under Calm Conditions

File Name	Reported Thickness * (mm/% cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
U101300A	0.0					Reference
U101300B	0.0	0.000	4.450	0.000	0.000	0.000
U101300C	0.0	0.000	4.450	0.000	0.000	0.000
U101305A	0.92/50%	0.500	1.450	0.475	0.475	0.475
U101305B	0.92/50%	0.550	1.425	0.550	0.550	0.550
U101305C	0.92/50%	0.525	4.325	0.525	0.525	0.525
U101310A	1.3/70% - 80%	2.200	1.850	2.300	2.200	1.850
U101310B	1.3/70% - 80%	2.300	1.875	2.375	2.300	1.80 - 1.90
U101310C	1.3/70% - 80%	1.000	1.700	1.000	1.000	1.00 or 1.70
U101310D	1.3/70% - 80%	1.075	1.675	1.075	1.075	1.075 or 1.70
U101320A	2.1/95%	3.150	6.225	3.225	3.175	3.175
U101320B	2.1/95%	3.150	3.050	3.175	3.150	3.150
U101320C	2.1/95%	2.675	2.300	2.700	2.675	2.300
U101320D	2.1/95%	3.025	2.775	3.075	3.000	3.000
U1013221	2.1/95%	2.625	2.125	2.650	2.625	2.625 or 2.10
U1013230	3.0/100%	3.675	3.900	3.525	3.600	3.40 - 3.90
U1013280	8.0/100%	9.875	3.375	0.925	9.875	9.875

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

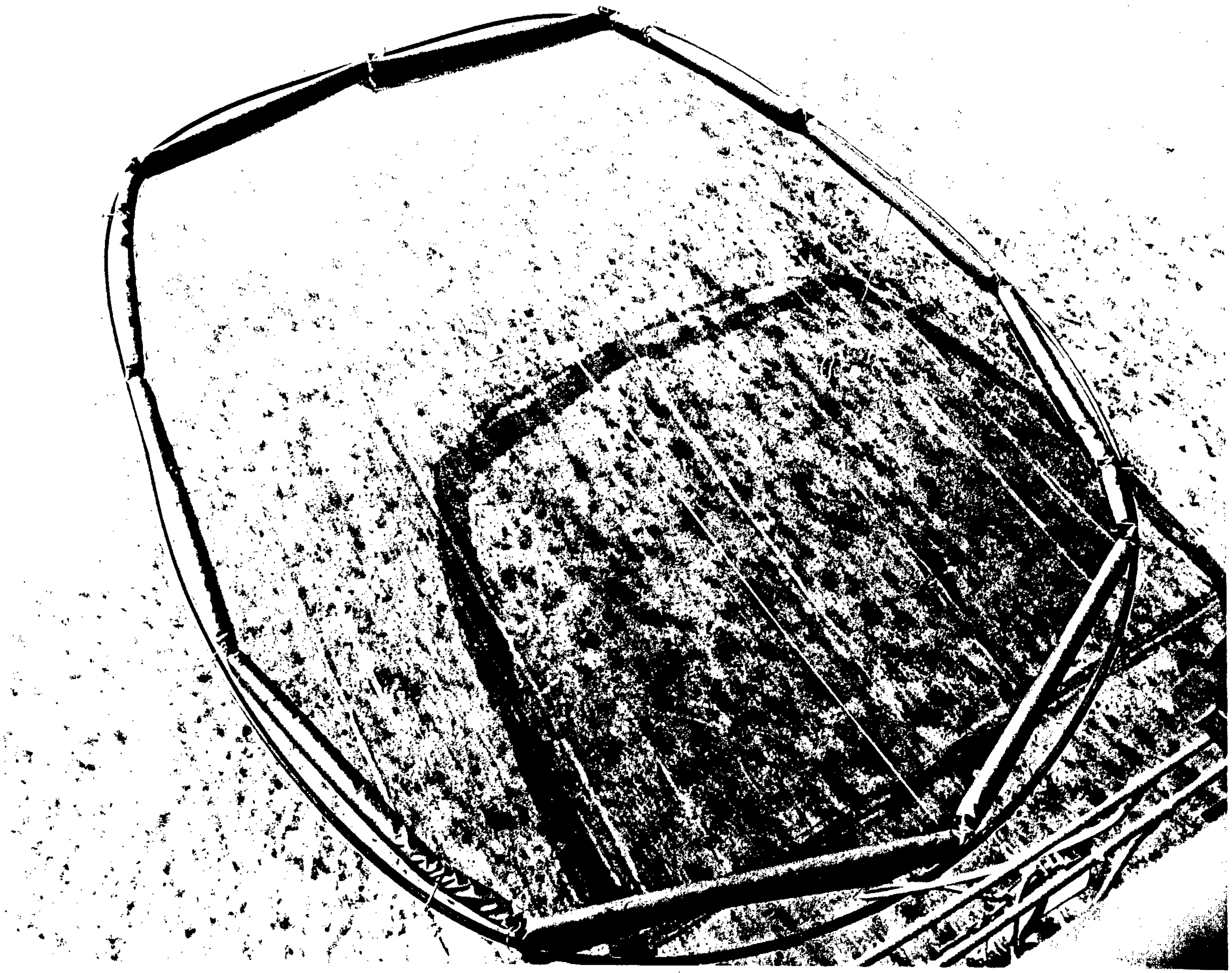

Figure 4-2 Photograph of Dyed Diesel 1.0 mm Oil Target Under Calm Conditions, 13 October 1994

4.2.4 Analysis of 14 October Measurements

The data collected on 14 October was a continuation of the Type 1 oil measurements. The oil target pools consisted of dyed diesel oil. These target pools, which had settled overnight, had been used for wave 1 and wave 2 conditions on 13 October. It appeared that only a small volume of oil had escaped from the pools during wave conditions so the volume of oil in each target pool should have remained nearly unchanged from the previous day. The T^B versus frequency curves for this data set are contained in Appendix D.

Table 4-5 documents the results of the 14 October 1994 dyed diesel oil measurements for each of the methods used by the thickness estimation algorithm. In all cases but the 2.0 mm (intended thickness) measurements, the algorithm output compares favorably with the visual analysis of the T^B versus frequency curves. In turn, the visual analysis compares reasonably well with the OHMSETT reported thickness. Some of the 2.0 mm (intended thickness) measurements did not match the theoretical predictions well based on visual analysis of the T^B versus frequency curves. One possible explanation is that, as indicated in the on-site notes, some type of pollen or dust had settled on the surface. However, it seems that if the inconclusive curves are compared as a group within the measurement set, the results seem to be consistent. In the case of H101420A, the curve might be considered to be in the 3.3 mm range based on overall T^B and shape and this would be consistent with the H101420B measurement and the on-site notes that the oil appeared thicker on this side of the oil target. The next two measurements (H101420C, D) were from the center of the target, have a somewhat similar appearance, and indicate a thinner oil film of approximately 3.0 mm. The final three measurements (H101420E through G) again have a similar curvature (though the overall T^B seems to drift) and these indicate an oil thickness of about 2.2 mm.

Table 4-5. Results of 14 October 1994 Measurements of Dyed Diesel Oil Under Calm Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
H101400A	0.0	0.000	7.575	0.000	0.000	0.000
H101400B	0.0	0.000	4.550	0.000	0.000	0.000
H101400C	0.0					Reference
H101400D	0.0	0.000	4.475	0.000	0.000	0.000
H101405A	1.0/50%	0.750	4.375	0.750	0.750	0.750
H101405B	1.0/50%	0.725	4.250	0.725	0.725	0.725
H101405C	1.0/50%	0.725	4.350	0.725	0.725	0.725
H101405D	1.0/50%	0.475	4.500	0.475	0.475	0.475
H101405E	1.0/50%	0.500	1.475	0.500	0.500	0.500
H101405F	1.0/50%	0.525	4.425	0.525	0.525	0.525
H101405G	1.0/50%	0.325	4.550	0.350	0.325	0.325
H101405H	1.0/50%	0.275	4.575	0.275	0.275	0.275
H101410A	1.4/70%	1.150	4.775	1.125	1.125	1.200
H101410B	1.4/70%	1.200	1.650	1.175	1.175	1.175 or 1.6
H101410C	1.4/70%	1.150	1.650	1.150	1.150	1.150 or 1.6
H101410D	1.4/70%	0.500	1.325	0.500	0.500	0.500
H101410E	1.4/70%	0.500	1.300	0.500	0.500	0.500
H101410F	1.4/70%	0.400	4.525	3.375	0.400	0.400
H101410G	1.4/70%	0.375	4.525	0.375	0.375	0.375
H101420A	2.2/90%	3.300	3.350	3.325	3.325	Inconclusive
H101420B	2.2/90%	3.350	3.475	3.350	3.350	3.350
H101420C	2.2/90%	2.975	2.700	2.950	2.950	Inconclusive
H101420D	2.2/90%	3.000	2.875	3.000	3.000	3.000
H101420E	2.2/90%	2.425	2.075	2.425	2.425†	Inconclusive
H101420F	2.2/90%	2.275	2.025	2.300	2.275	2.275
H101420G	2.2/90%	2.325	2.025	2.350	2.325	Inconclusive

Table 4-5. Results of 14 October 1994 Measurements of Dyed Diesel Oil Under Calm Conditions (cont.)

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
H101430A	3.2/95%	3.900	4.050	3.900	3.900	3.900
H101430B	3.2/95%	3.825	4.025	3.800	3.800	3.800
H101430C	3.2/95%	4.025	4.175	0.725	4.100	4.225
H101430D	3.2/95%	3.675	3.675	0.400	3.675	3.675
H101430E	3.2/95%	3.575	3.775	3.575	3.575	3.575
H101430F	3.2/95%	3.425	3.550	0.350	3.525	3.525
H101430G	3.2/95%	3.300	6.875	0.375	3.300	3.300
H101480A	8.0/100%	8.625	1.825	0.700	8.625	8.625
H101480B	8.0/100%	8.850	8.825	0.700	8.825	8.825
H101480C	8.0/100%	8.725	5.200	0.675	8.725	8.725
H101480D	8.0/100%	8.775	5.200	0.700	8.775	8.775
H101480E	8.0/100%	8.700	5.200	0.700	8.700	8.700
H101480F	8.0/100%	8.625	1.825	0.700	8.625	8.625
H101480G	8.0/100%	8.750	5.200	0.700	8.750	8.750
H101480H	8.0/100%	8.600	1.825	0.725	8.600	8.600

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

† The plotted T^B versus frequency curve is different from the algorithm estimate. The reason for the difference is explained in the text of the appendix.

Note that in the 1.0 mm measurements, a thickness gradient was observed over the length of the oil target (1.2 mm at the north end, 0.5 mm in the center, and 0.375 mm at the south end). This gradient was noted in the on-site comments and confirmed upon review of the OHMSETT down-looking camera videotapes. Although Figure 4-2 was taken a day earlier, it illustrates the same oil target with a similar oil gradient, although less pronounced.

4.2.5 Analysis of 17 October Measurements

Oil targets for the 17 October measurements consisted of the Type 2 blended crude oil, with the volume overfilled by 25% to allow evaporation of lighter volatile hydrocarbon products. The T^B versus frequency curves for this data set are contained in Appendix E. The pools that contained less than 80% anticipated coverage area created oil targets that tended to remain clumped together, close to the containment booms. In some measurements, the entire antenna footprint was not completely filled; these are noted in the log and in the comments in Appendix E. The fact that the antenna beam fill was not complete alters the expected T^B versus frequency signature. There will be less amplitude modulation of the brightness temperature because the percentage of maximum possible amplitude modulation that actually occurs is directly related to the antenna beam fill percentage. During the analysis, when the measured and estimated curves do not match well, and the notes indicate a less than uniform oil coverage in the antenna footprint, an attempt was made to use the observed percent antenna beam fill and an estimated oil curve of the correct shape to match the data. This was accomplished by calculating a weighted average of water and oil brightness temperatures over the FSR frequency band. This approach proved somewhat successful; however, it was observed that low percentage beam fill results (e.g., 1.4 mm at 15% fill) can appear very similar to full beam thin oil results (e.g., 0.4 mm at 100%).

Table 4-6 documents the results of the 17 October 1994 crude oil measurements for each of the methods used by the thickness estimation algorithm. The best results were obtained when measurements were made over the high-intended-percentage filled oil pools (80% and 100%). In these cases, the algorithm thickness estimates and visual analyses agree, although the estimates in the case of the 100% filled pool (L101725A through C) seem high compared to the OHMSETT-reported thickness, and the results of the 80% (intended fill) pool (L102580A through E) seem low even when allowing for the

extra spreading to 90% coverage. Most of the initial measurements from the 10% (intended fill) pool were inconclusive; the first four passes (L102510A through D) were made in an area of the oil target that had a discolored (somewhat clear but amber-tinted surface; not black like the heavier areas of crude oil) "scummy" surface. The 10% (intended coverage) pool is illustrated in figure 4-3. The "scummy" surface is an area of discoloration at the top of the photo; this image of the discoloration did not reproduce well between the original color photograph and the final black-and-white copy shown here. When the antenna footprint was partially filled with heavier crude oil (L102510F - H), and the percentage of antenna beam fill is taken into account, the results are consistent. Finally, the last three measurements were made over an oil surface that appeared to fully fill the antenna footprint, namely, the area of dark oil at the bottom of the photograph. The best matches were obtained when an 85 percent beam fill estimate was compared to the measured data. Based on the good results over the black crude oil, it might be speculated that the "scummy" surface, although being a product that leached from the oil, did not have a dielectric characteristic similar to pure crude oil.

The 40% (intended fill) oil target pool is another case where the estimation of oil film thickness is dependent upon the antenna beam fill percentage. Figure 4-4 is a photograph of this oil target. Note that the oil seemed to fill most of the target area, which meant that the antenna footprint should have had a high percentage of beam fill. The first three measurements (L102540A - C) were collected in the oil-covered area shown at the top of the photo. The estimates here show a reasonably good comparison to the reported thickness. The next two measurements (L102540D, E) were from the center of the oil pool where the top strip of water is visible in the photo. The results here are consistent if the effect of partial antenna beam fill is considered. The final four measurements (L102540F - I) were collected over the oil/water area shown at the bottom of the photo. The curves associated with these measurements could not be matched

to typical theoretical predictions even when partial antenna beam fill effects were taken into account, leading to inconclusive results.

The three measurements collected over the 20% (intended coverage) oil target (L102520A - C) appear to be consistent with each other. When the antenna beam fill is taken into account the results seem to be a good match with the on-site reported thickness.

Table 4-6. Results of 17 October 1994 Measurements of Crude Oil Under Calm Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm) (% Fill)
L101700A	0.0					Reference
L101700B	0.0	0.000	1.600	0.000	0.000	0.000
L101700C	0.0	0.000	1.450	0.000	0.000	0.000
L101725A	3.5/100%	4.600	4.325	1.175	4.600	4.375
L101725B	3.5/100%	4.600	4.300	1.150	4.600	4.300
L101725C	3.5/100%	4.575	4.325	1.100	4.450	4.450
L102510A	3.1/10%	0.000	9.075	0.000	0.000	Inconclusive
L102510B	3.1/10%	0.000	9.025	0.000	0.000	Inconclusive
L102510C	3.1/10%	0.150	0.575	0.150	0.150	0.150
L102510D	3.1/10%	0.000	0.375	0.000	0.000	0.000
L102510E	3.1/10%	0.000	0.000	0.000	0.000	0.000
L102510F	3.1/10%	0.675	0.000	0.675	0.675	1.9 @ 40%
L102510G	3.1/10%	0.625	9.200	0.625	0.625	1.9 @ 35%
L102510H	3.1/10%	0.650	9.450	0.675	0.650	1.9 @ 35%
L102510I	3.1/10%	1.250	1.650	1.225	1.225	1.5 @ 85%

Table 4-6. Results of 17 October 1994 Measurements of Crude Oil Under Calm Conditions (cont.)

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
L102510J	3.1/10%	1.175	1.700	1.175	1.175	1.5 @ 85%
L102510K	3.1/10%	1.225	1.700	1.200	1.200	1.5 @ 85%
L102520A	1.65/40%	0.700	1.750	0.725	0.700	1.8 @ 40%
L102520B	1.65/40%	0.625	1.650	0.650	0.625	1.8 @ 40%
L102520C	1.65/40%	0.750	1.725	0.775	0.750	1.8 @ 40%
L102540A	1.65/80%	2.700	2.600	2.675	2.675	2.675
L102540B	1.65/80%	2.650	2.500	2.650	2.650	2.650
L102540C	1.65/80%	2.550	2.650	2.550	2.550	2.550
L102540D	1.65/80%	2.375	1.900	2.425	2.400	2.0 @ 70%
L102540E	1.65/80%	2.475	5.475	0.900	2.475	2.0 @ 65%
L102540F	1.65/80%	0.850	1.725	0.875	0.850	Inconclusive
L102540G	1.65/80%	0.725	1.675	0.750	0.725	1.8 @ 40%
L102540H	1.65/80%	0.750	9.550	0.775	0.750	Inconclusive
L102540I	1.65/80%	0.725	9.750	0.750	0.725	Inconclusive
L102580A	2.9/98%	1.250	3.825	1.225	1.225	1.225
L102580B	2.9/98%	1.325	3.800	1.300	1.300	1.300
L102580C	2.9/98%	1.350	3.825	1.350	1.350	1.350
L102580D	2.9/98%	2.125	8.200	2.225	2.175	1.8 @ 80%
L102580E	2.9/98%	2.425	2.450	2.450	2.450	Inconclusive

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

Figure 4-3 Photograph of Crude Oil 2.5 mm Oil Target with 10% Surface Area Coverage Under Calm Conditions, 17 October 1994

Figure 4-4 Photograph of Crude Oil 2.5 mm Oil Target with 40% Surface Area Coverage Under Calm Conditions, 17 October 1994

4.2.6 Analysis of 18 October Measurements

The oil targets for the 18 October measurements consisted of the Type 2 blended crude oil which had been on the water overnight to allow evaporation of lighter volatile hydrocarbon products. It was estimated that approximately 25% of the volume of oil in each pool would evaporate overnight. The pools that contained less than 80% anticipated coverage created oil targets that remained close to the containment booms. In some measurements, the entire antenna footprint was not completely filled; these are noted in the log and in the comments in Appendix E. As discussed in section 4.2.5, the fact that the antenna beam fill was not complete alters the expected T^B versus frequency signature. In cases where it was apparent that less than full antenna beam fill affected the measurements, an estimate was made of oil thickness and beam fill percentage based on the visual analysis of the oil T^B curves. The T^B versus frequency curves for this data set are contained in Appendix E.

After completing initial uniform thickness measurements, the oil in each of the pools was stirred to create "clumpy" oil patches, and another data set was collected on the patchy oil under calm conditions. Figures 4-5 through 4-8 illustrate the appearance of the oil targets under calm wave conditions after they had been disturbed by stirring with a boat-hook. The stirring caused a distinct change in the texture of the oil target surface. In the fuller pools, measurements could be made later on both disturbed and undisturbed parts of the target (figures 4-5, 4-7, 4-8). In low-percentage fill targets, all of the oil was disturbed (figure 4-6).

Table 4-7 documents the results of the 18 October 1994 crude oil measurements for each of the methods used by the thickness estimation algorithm. The results in *italics* indicate the measurements from the disturbed areas of the oil targets.

Overall, the estimates of oil thickness over the undisturbed oil targets agree reasonably well with the OHMSETT-reported thicknesses. In the case of the 100% (intended coverage) pool (M182500A through D), it is difficult to determine if the thickness is about 0.7 mm or about 3.8 mm; the T^B curve seems to have a shape similar to the expected 3.8 mm prediction but the measured temperature at the lower frequencies is too high. Because of these higher measured T^B's there seems be a better match to the 0.7 mm estimate.

The 20% (intended coverage) target only partially filled the antenna beam. The first three measurements (M182520A - C) were collected over the same spot on the oil target, and not surprisingly the plots appear consistently shaped. Taking a partial beam fill approach, the 1.4 mm estimate at 60% beam fill matches the measured data. This estimate seems low compared to the on-site notes reflecting a 90% beam fill, but the discrepancy may be attributable to a simple beam fill estimation error by the FSR operator. The next two measurements were taken over a different part of the oil target, and these two estimates seem consistent at 0.4 - 0.5 mm; it should be noted that these two measurements were taken over an area of scattered oil blobs and oil sheen that were present before the pool was stirred.

The 40% (intended coverage) measurements (M182540A - C) are a good match to a 2.1 mm thickness with partial beam fill which seems to agree with the OHMSETT-reported thickness. The 80% (intended coverage) pool measurements (M182580A through C) seem to indicate a thickness of 2.5 to 2.9 mm; this seems reasonable because it was the intended oil target thickness. Finally, the results from the 10% (intended coverage) pools (M18BASEA, B) match well with an 80 - 90% partial antenna beam fill of 1.8 mm oil.

After the pools had been stirred, many measurements (M182500E through G, M182520F & G, and M182580D through F) produced a high T^B and flat curve

shape indicative of bubbles or emulsion or a lower T^B with flat response indicating an inconclusive result. Figures 4-5 through 4-8 illustrate the appearance of the oil film after it was stirred; as can be seen, the oil no longer forms a nicely-distributed uniform layer. Although the oil was disturbed, some care was taken not to intentionally mix in any water. The photos and videotape show that the appearance of the oil surface did not vary appreciably between pools. After a short settling period, some success in measuring the oil thickness of these targets was achieved. The 20% (intended coverage) pool results (M182520H - L) seem consistent; it should be noted that although the antenna beam was only partially filled with oil, the thickness estimates here assume full oil coverage. This may have occurred because T^B curves for low-percentage beam fills of 1.4 - 1.8 mm oil when averaged with water are nearly identical to full-coverage estimates for oil alone at 0.4 - 0.6 mm thickness. The 40% (intended coverage) results (M182540D - G) again seem consistent with the reported thickness and on-site antenna beam fill percentages. The results from the last two measurements over the 80% coverage pool (M182580G, H) show similar results, but with poor agreement between reported and measured thickness of the oil-covered surface.

Table 4-7. Results of 18 October 1994 Measurements of Crude Oil Under Calm Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm) (% Fill)
M180000A	0.0					Reference
M180000B	0.0	0.000	1.550	0.000	0.000	0.000
M180000C	0.0	0.000	1.500	0.000	0.000	0.000
M182500A	3.75/80%	0.750	3.750	0.725	0.725	0.725 or 3.75
M182500B	3.75/80%	0.725	3.775	0.700	0.700	0.70 or 3.8
M182500C	3.75/80%	0.700	3.775	0.700	0.700	0.70 or 3.8
M182500D	3.75/80%	0.675	3.725	0.675	0.675	0.675
M182500E	*3.75/80%*	*1.725*	*1.825*	*1.675*	*1.700*	*1.825 or Emulsion*
M182500F	*3.75/80%*	*1.725*	*1.825*	*1.675*	*1.700*	*1.800 or Emulsion*
M182500G	*3.75/80%*	*1.725*	*1.800*	*1.675*	*1.700*	*1.800 or Emulsion*
M182500H	*3.75/80%*	*2.150*	*1.850*	*2.225*	*2.175*	*1.85 @ 80%*
M182500I	*3.75/80%*	*1.950*	*1.875*	*2.025*	*1.900*	*1.900*
M182500J	*3.75/80%*	*1.700*	*8.000*	*1.675*	*1.675*	*Emulsion*
M182500K	*3.75/80%*	*1.700*	*1.700*	*1.675*	*1.700*	*1.70 or Emulsion*
M182520A	2.8/20%	0.825	1.550	0.825	0.825	1.4 @ 60%
M182520B	2.8/20%	0.850	1.625	0.850	0.850	1.4 @ 60%
M182520C	2.8/20%	0.900	1.675	0.900	0.900	1.4 @ 60%
M182520D	2.8/20%	0.500	0.175	0.500	0.500	0.500
M182520E	2.8/20%	0.400	1.600	0.400	0.400	0.400
M182520F	*2.8/20%*	*1.800*	*5.050*	*2.000*	*1.900†*	*Inconclusive*
M182520G	*2.8/20%*	*1.825*	*7.725*	*2.000*	*1.900*	*Inconclusive*
M182520H	*2.8/20%*	*1.675*	*4.675*	*1.850*	*1.750*	*1.750*
M182520I	*2.8/20%*	*0.650*	*1.600*	*0.675*	*0.650*	*0.65 or 1.6*

Table 4-7. Results of 18 October 1994 Measurements of Crude Oil Under Calm Conditions (cont.)

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
M182520J	2.8/20%	0.550	1.250	0.550	0.550	0.550
M182520K	2.8/20%	0.475	0.400	3.625	0.425	0.425
M182520L	2.8/20%	0.500	1.500	0.500	0.500	0.500
M182540A	1.9/60%	2.350	2.025	2.375	2.350	2.1 @ 80%
M182540B	1.9/60%	2.250	1.975	2.275	2.250	2.1 @ 85%
M182540C	1.9/60%	2.225	5.450	2.275	2.250	2.1 @ 85%
M182540D	1.9/60%	0.725	4.700	0.750	0.725	1.8 @ 40%
M182540E	1.9/60%	0.675	1.625	0.675	0.675	1.8 @ 35%
M182540F	1.9/60%	0.975	1.525	0.975	0.975	1.5 @ 65%
M182540G	1.9/60%	0.950	4.600	0.950	0.950	1.5 @ 65%
M182540H	1.9/60%	1.950	7.725	2.050	2.000	Inconclusive
M182540I	1.9/60%	2.025	7.550	2.100	2.050	Inconclusive
M182580A	3.75/80%	2.550	2.900	2.550	2.550	2.55 or 2.9
M182580B	3.75/80%	2.525	6.075	2.550	2.525	2.525
M182580C	3.75/80%	2.400	6.275	0.950	2.400	Inconclusive
M182580D	3.75/80%	1.700	8.025	1.675	1.675	Emulsion
M182580E	3.75/80%	1.700	8.225	1.675	1.675	Emulsion
M182580F	3.75/80%	1.700	7.975	1.675	1.675	Emulsion
M182580G	3.75/80%	1.900	1.725	1.300	1.800	1.8 @ 90%
M182580H	3.75/80%	1.250	1.625	1.225	1.225	1.8 @ 85%
M18BASEA	2.5/10%	1.150	1.775	1.150	1.150	1.8 @ 80%
M18BASEB	2.5/10%	1.325	4.950	2.100	1.325	1.8 @ 90%

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

† The plotted T^B versus frequency curve is different from the algorithm estimate. The reason for the difference is explained in the text of the appendix.

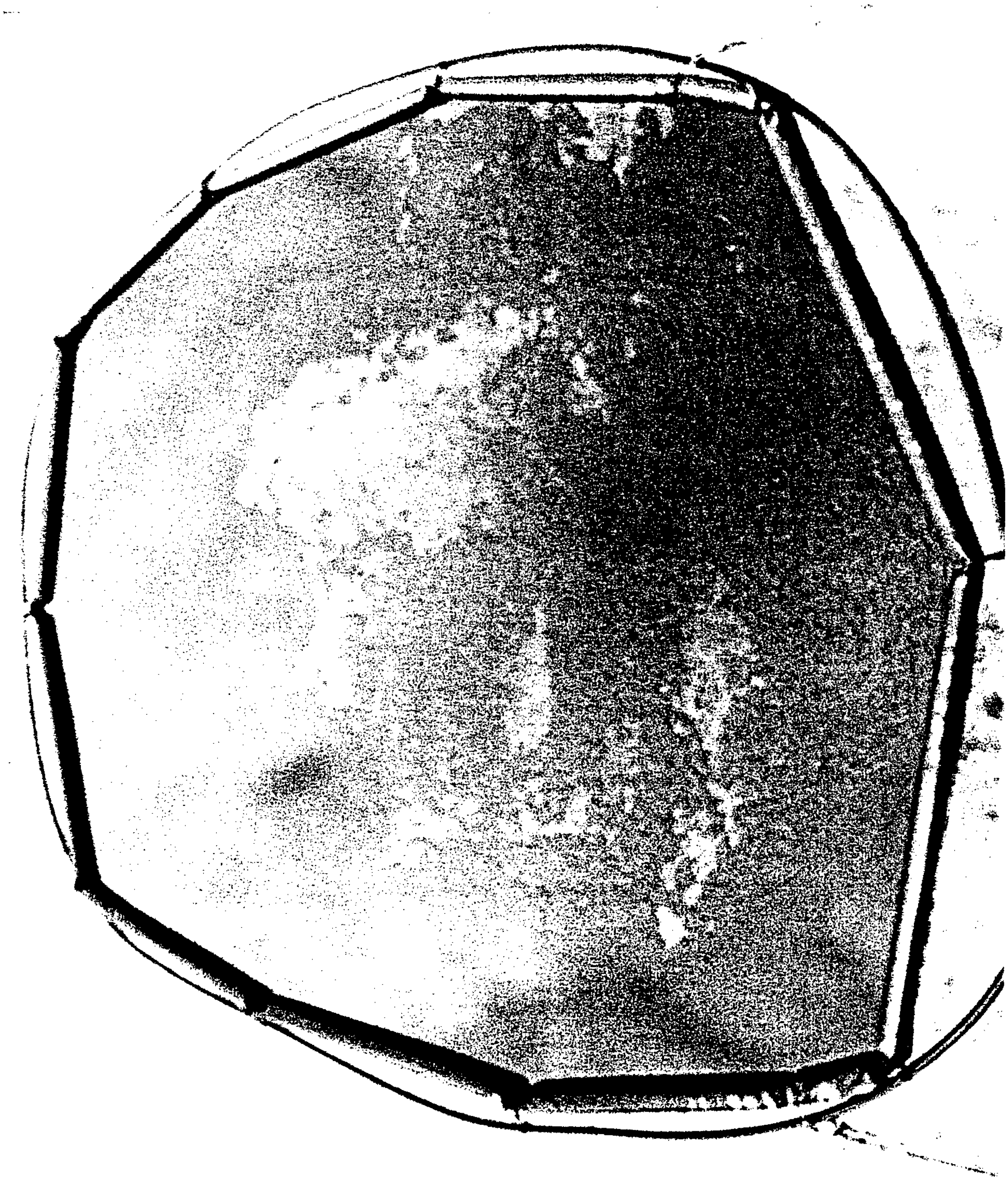

Figure 4-5 Photograph of Crude Oil 2.5 mm Oil Target with 100% Surface Area Coverage Under Calm Conditions, 18 October 1994 After Pool was Stirred

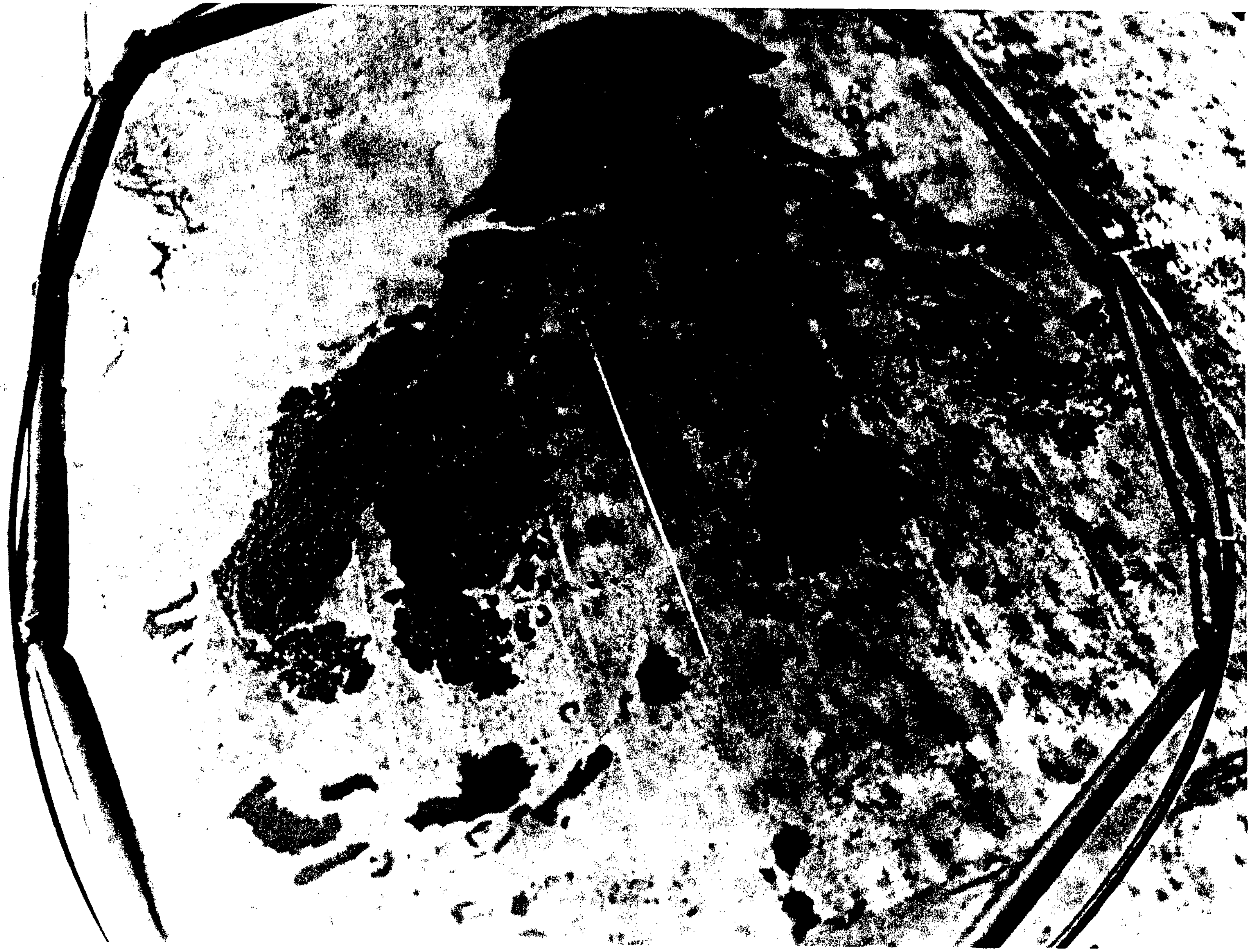

Figure 4-6 Photograph of Crude Oil 2.5 mm Oil Target with 20% Surface Area Coverage Under Calm Conditions. 18 October 1994 After Pool was Stirred

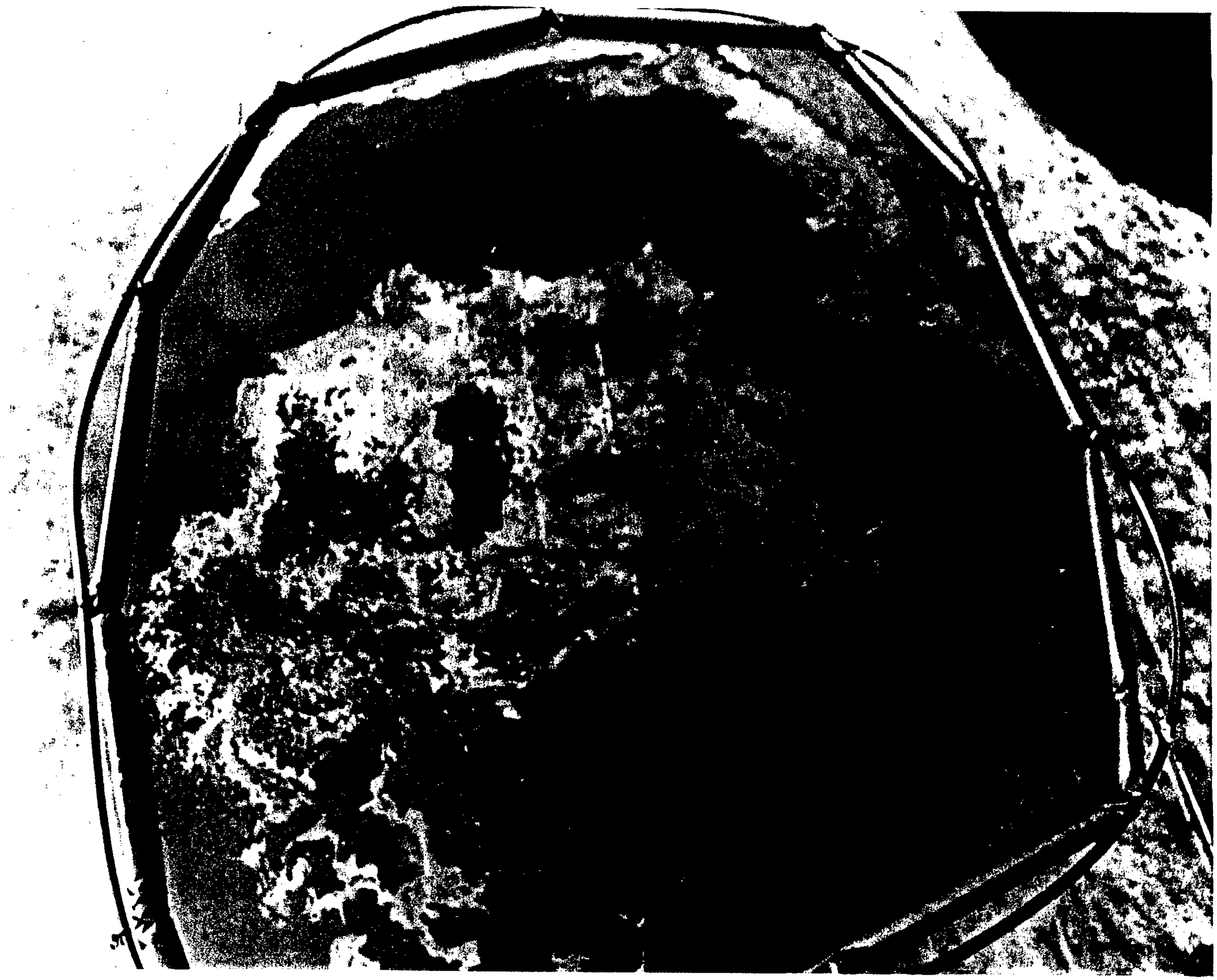

Figure 4-7 Photograph of Crude Oil 2.5 mm Oil Target with 40% Surface Area Coverage Under Calm Conditions, 18 October 1994 After Pool was Stirred

Figure 4-8 Photograph of Crude Oil 2.5 mm Oil Target with 80% Surface Area
Coverage Under Calm Conditions, 18 October 1994 After Pool was Stirred

4.2.7 Analysis of 19 October Measurements

Table 4-8 documents the results from the measurements collected over oil targets of unknown thickness. Each set of measured data was immediately compared to the laptop-generated theoretical predictions, and measurement sweeps were collected over each target until the FSR operator felt confident that the oil thickness could be estimated. The results of the visual analysis compare favorably with all oil targets except target 2; however, based on the large number of data files that agree, it is believed that the oil target was thicker than reported. The T^B versus frequency curves for this data set are contained in Appendix G.

Note that pools 4 and 5 did show an emulsion characteristic. Referring to figure 4-9, the first three measurements over target pool 4 (UNK04A - C) were in the "swirly" area shown in the center of the photograph. This pool was composed of a combination of OHMSETT waste oil and diesel oil; the swirly area may be an area where the oils did not mix well, and the waste oil may have had a somewhat high water content that would cause an emulsion-like FSR signature. The last three measurements over target 4 (UNK04D - F) were from a different area of the oil target that had a more uniform appearance (i.e., color, texture). These three measurements show good agreement with the reported thickness. A photograph of target 5 is shown in figure 4-10. Note that the surface of this target has a somewhat mottled appearance. The first four measurements (UNK05A - D) were collected over the same area near the center of the oil target, and all of the results appear emulsion-like. After the aimpoint was moved to the northeast (the bottom right portion of the pool in figure 4-10), the results were more consistent with the reported thickness. Based on these two observations, it can be hypothesized that the homogeneity of the oil seems to affect the thickness measurement capability of the FSR.

Note that the first measurement of water indicates a false positive indication of oil. It is believed that the heated electronics assembly in the instrument had not reached equilibrium, so a later measurement was used as the background water reference for analysis purposes.

Table 4-8. Results of 19 October 1994 Measurements of Unknowns Under Calm Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
UNKREFA	0.0	0.275	7.400	0.275	0.275	0.275
UNKREFB	0.0					Reference
UNKREFC	0.0	0.000	7.675	0.000	0.000	0.000
UNK01A	0.74/90%	0.825	1.470	0.800	0.800	0.800
UNK01B	0.74/90%	0.600	3.900	0.575	0.575	0.575
UNK01C	0.74/90%	0.450	4.075	3.500	0.450	0.450
UNK01D	0.74/90%	0.975	1.200	0.950	0.950	0.950
UNK01E	0.74/90%	0.900	4.425	0.900	0.900	0.900
UNK01F	0.74/90%	0.975	1.575	0.975	0.975	0.975
UNK01G	0.74/90%	1.000	1.525	0.975	0.975	0.975
UNK02A	2.6/100%	0.250	7.725	0.275	0.250	0.250
UNK02B	2.6/100%	3.400	3.450	0.450	3.450	3.450
UNK02C	2.6/100%	3.425	3.575	0.375	3.400	3.400
UNK02D	2.6/100%	3.350	3.400	3.325	3.400	3.400
UNK02E	2.6/100%	3.400	3.425	0.475	3.400	3.400
UNKA2A	2.6/100%	3.850	3.900	3.875	3.875	3.875
UNKA2B	2.6/100%	3.725	3.825	3.775	3.800	3.800
UNKA2C	2.6/100%	3.600	7.100	0.500	3.600	3.600
UNKA2D	2.6/100%	3.625	3.700	0.500	3.650	3.650
UNKA2E	2.6/100%	0.600	3.500	0.600	0.600	Inconclusive
UNKA2F	2.6/100%	3.400	3.550	0.375	3.475	3.475

Table 4-8. Results of 19 October 1994 Measurements of Unknowns Under Calm Conditions (cont.)

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
UNKA2G	2.6/100%	3.250	3.250	3.275	3.250	3.250
UNKA2H	2.6/100%	3.450	3.525	3.525	3.525	Inconclusive
UNK03A	2.0/100%	2.125	1.925	2.150	2.125	1.9 - 2.2
UNK03B	2.0/100%	2.200	1.950	2.225	2.200	1.9 - 2.2
UNK03C	2.0/100%	2.150	1.925	2.200	2.125	1.9 - 2.2
UNK03D	2.0/100%	1.050	8.200	2.325	1.050	Inconclusive
UNK03E	2.0/100%	1.925	5.375	1.875	1.900	1.9 or 5.5 Partial
UNK03F	2.0/100%	2.150	5.700	2.150	2.150	2.150
UNK03G	2.0/100%	2.125	2.100	2.075	2.100	2.100
UNK03H	2.0/100%	2.200	2.200	2.225	2.200	2.200
UNK04A	1.7/60%	1.700	8.050	1.675	1.675	Emulsion
UNK04B	1.7/60%	1.700	8.075	1.675	1.675	Emulsion
UNK04C	1.7/60%	1.700	8.150	1.675	1.675	Emulsion
UNK04D	1.7/60%	1.400	4.600	1.400	1.400	1.400
UNK04E	1.7/60%	1.500	1.650	1.575	1.600	1.600
UNK04F	1.7/60%	1.400	1.625	1.425	1.400	1.400
UNK05A	2.5/100%	1.725	1.900	1.675	1.700	Emulsion
UNK05B	2.5/100%	1.750	1.925	1.675	1.700	Emulsion
UNK05C	2.5/100%	1.800	5.825	1.700	1.750	Emulsion
UNK05D	2.5/100%	1.800	2.150	1.700	1.750	Emulsion
UNK05E	2.5/100%	2.250	2.150	2.250	2.250	2.250
UNK05F	2.5/100%	2.250	3.025	2.250	2.250	2.25 or 3.0

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

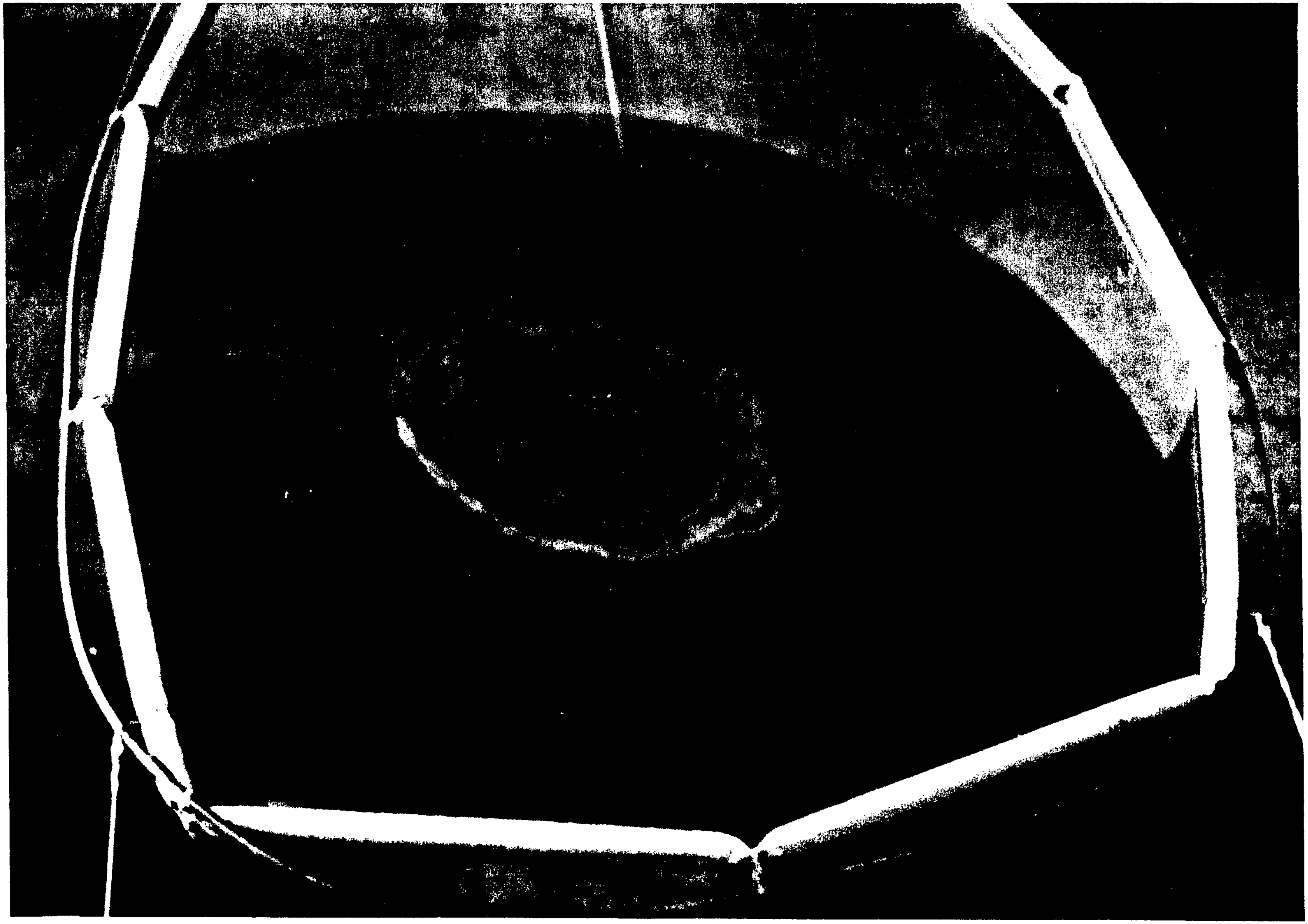

Figure 4-9 Photograph of "Unknown" Target Pool 4 Under Calm Conditions, 19 October 1994

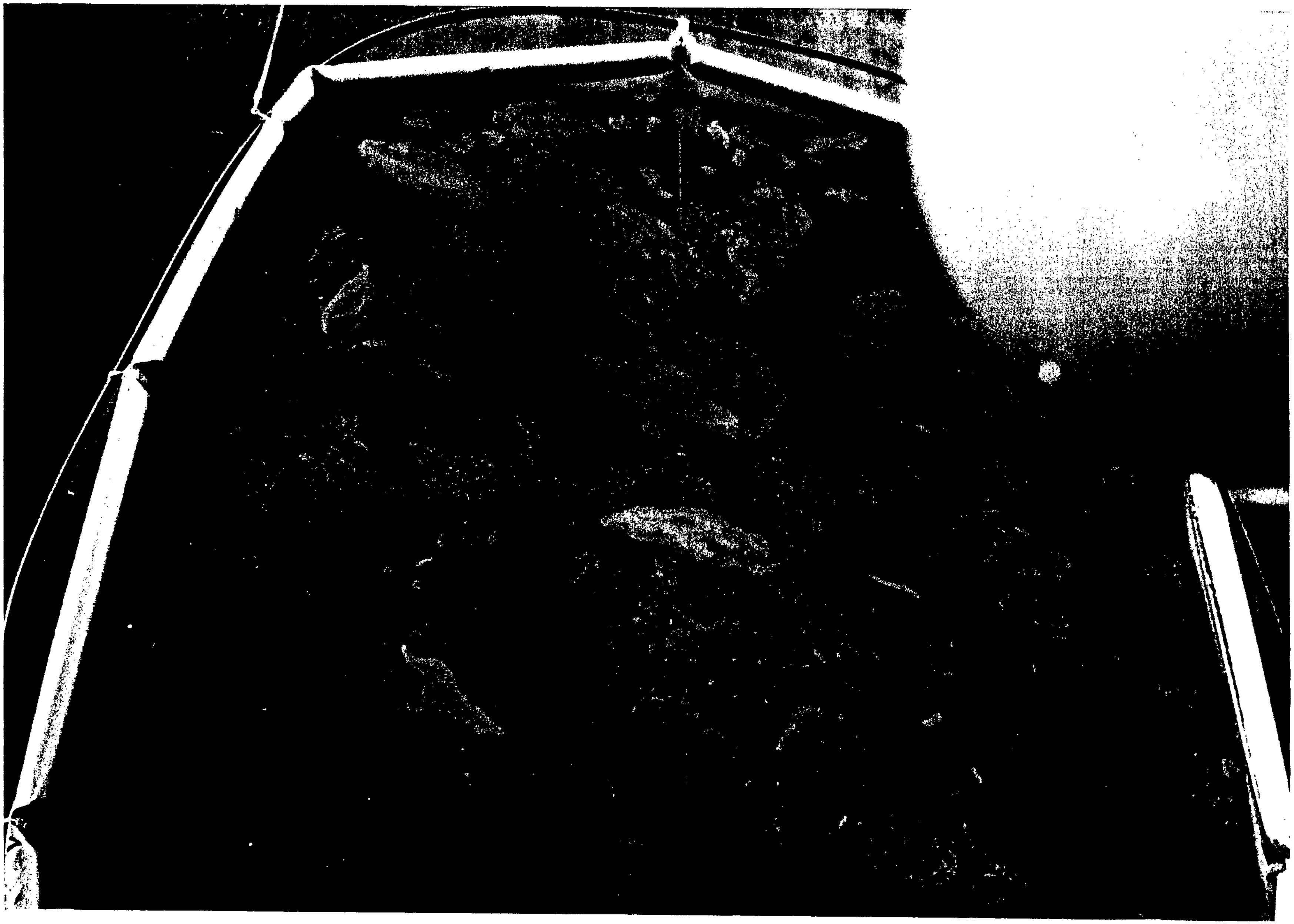

Figure 4-10 Photograph of “Unknown” Target Pool 5 Under Calm Conditions, 19 October 1994

4.3 WAVE CONDITIONS

The results from the FSR measurements collected under wave conditions are mixed. Under wave 1 conditions, the FSR successfully measured thicknesses up 3.0 mm in both the diesel and the unknown pools, and with high antenna beam fill percentages, the FSR was successful in measuring the crude oil. The results obtained under wave 2 conditions indicate the FSR was not capable of measuring diesel or crude oil, possibly because of the surface perturbations (bubbles/emulsification), but had limited success measuring the unknown oil targets.

4.3.1 Analysis of 12 October Wave 1 Condition Measurements

The data collected on 12 October 1994 was part of the dry-run measurements. The T^B versus frequency curves for this data set are contained in Appendix C. This was the first opportunity to collect data under wave conditions at the OHMSETT facility. The results in table 4-9 show that all of the visual analysis estimates show a reasonably good match to the reported thickness. Note that most of the algorithm results also matched the reported thickness, and in the one case where the algorithm-declared thickness differed, the correlation method result compared favorably with the actual thickness.

Table 4-9. Results of 12 October 1994 Measurements of Dyed Diesel Oil Under Wave 1 Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
E101200A	0.0					Reference
F101280A	8.0/100%	7.875	7.850	0.650	7.850	7.850
F101280B	8.0/100%	8.150	4.800	0.775	8.150	8.150
F101280C	8.0/100%	0.600	7.975	2.900	0.600	7.900
F101280D	8.0/100%	7.875	7.900	2.250	7.875	7.875

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

4.3.2 Analysis of 13 October Wave 1 Condition Measurements

Table 4-10 contains the results of the dyed diesel measurements under wave 1 conditions. For comparison purposes, these measurements were collected after the calm condition measurements described in section 4.2.3. The T^B versus frequency curves for this data set are contained in Appendix D. The results of the 0.5 mm target pool measurements (V101305A - C) compare favorably with the calm measurements over the same pool (U101305A - C) as well as the measurements over the 3.0 mm target pool (V101330A, B, D - F compared to U1013230). The 1.0 mm target pool results (V101310D - F) are consistent with the visual observation recorded in the field notes that the measurements were collected over a thinner part of the oil target. Although

these estimated thicknesses do not match the calm measurements, they appear to be consistent.

Figure 4-11 illustrates the 2.0 mm oil target pool. Note the difference in appearance of the oil along the right side of the containment area; the bottom of the tank is visible in the lower right while the upper left area seems quite dark and has a higher concentration of water or air bubbles on the surface. The first three measurements (V101320A - C) were from the lower right quadrant of the containment area and the results, although thinner than expected, are consistent while the last three measurement sweeps (V10132D - F) from the upper left quadrant appear to be inconclusive.

The results from the 8.0 mm oil target pool were disappointing. The expected T^B versus frequency plot was to be a well-formed sinusoid; a review of the plots shows a flat response. In these light wave conditions, the oil seemed to form into lenses as shown in figure 4-12 and this may have contributed to the poor results. All of the measurements from this pool yielded inconclusive results.

Table 4-10. Results of 13 October 1994 Measurements of Dyed Diesel Oil Under Wave 1 Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
V101300A	0.0					Reference
V101300B	0.0	0.000	7.850	0.000	0.000	0.000
V101300C	0.0	0.000	7.800	0.000	0.000	0.000
V101300D	0.0	0.000	7.825	0.000	0.000	0.000
V101305A	1.0/50%	0.600	4.625	0.600	0.600	0.600
V101305B	1.0/50%	0.400	7.825	3.350	0.400	0.400
V101305C	1.0/50%	0.500	4.350	0.500	0.500	0.500
V101310A	1.4/70%	2.350	1.925	2.400	2.375	1.9 shape or Inconclusive
V101310B	1.4/70%	2.450	2.000	2.475	2.450	2.0 shape or Inconclusive
V101310C	1.4/70%	0.850	7.800	2.550	0.850	Inconclusive
V101310D	1.4/70%	0.575	4.300	0.575	0.575	0.575
V101310E	1.4/70%	0.725	4.300	0.725	0.725	0.725
V101310F	1.4/70%	0.775	4.325	0.775	0.775	0.775
V101320A	2.2/90%	0.325	7.675	0.325	0.325	0.325
V101320B	2.2/90%	0.375	7.675	3.350	0.375	0.375
V101320C	2.2/90%	0.450	7.750	3.200	0.450	0.450
V101320D	2.2/90%	2.950	2.750	2.875	2.900	Bad calibration
V101320E	2.2/90%	3.100	3.200	2.925	3.150	Inconclusive
V101320F	2.2/90%	2.850	2.825	2.800	2.825	2.825 or Inconclusive

Table 4-10. Results of 13 October 1994 Measurements of Dyed Diesel Oil Under Wave 1 Conditions (cont.)

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
V101330A	3.2/95%	3.350	7.100	3.250	3.300	3.300
V101330B	3.2/95%	3.750	3.875	0.600	3.800	3.800
V101330C	3.2/95%	0.450	7.375	3.125	0.450	0.450
V101330D	3.2/95%	4.025	4.200	0.725	4.100	4.100
V101330E	3.2/95%	4.075	4.200	0.750	4.125	4.125
V101330F	3.2/95%	4.025	4.125	0.750	4.075	4.075
V101380A	8.0/100%	0.825	1.625	0.850	0.825	Inconclusive
V101380B	8.0/100%	0.850	1.775	0.850	0.850	Inconclusive
V101380C	8.0/100%	0.900	1.775	0.925	0.900	Inconclusive
V101380D	8.0/100%	0.875	3.500	0.900	0.875	Inconclusive
V101380E	8.0/100%	0.925	9.750	0.950	0.925	Inconclusive

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

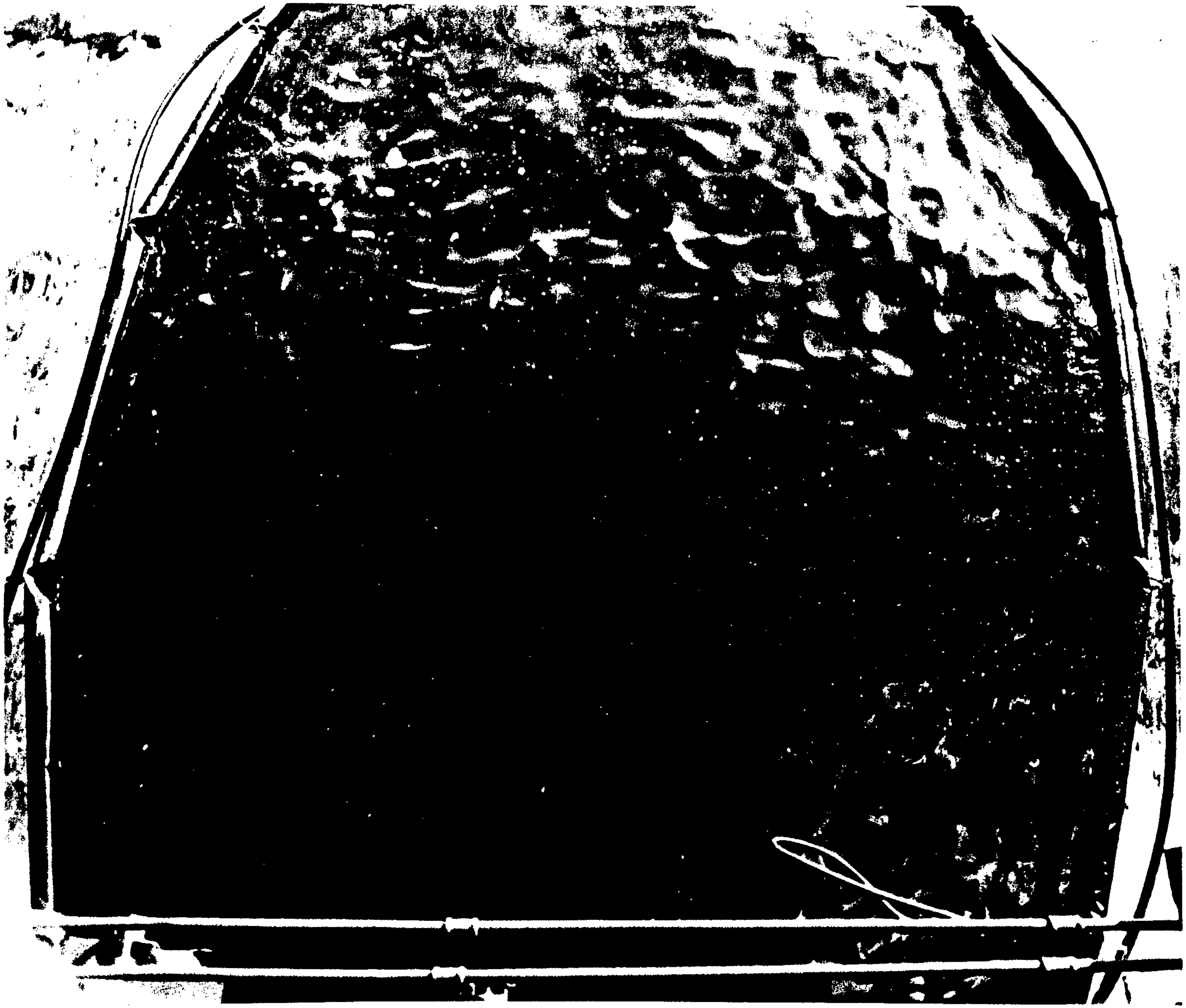

Figure 4-11 Photograph of 2.0 mm Diesel Oil Target Under Wave 1 Conditions, 13 October 1994

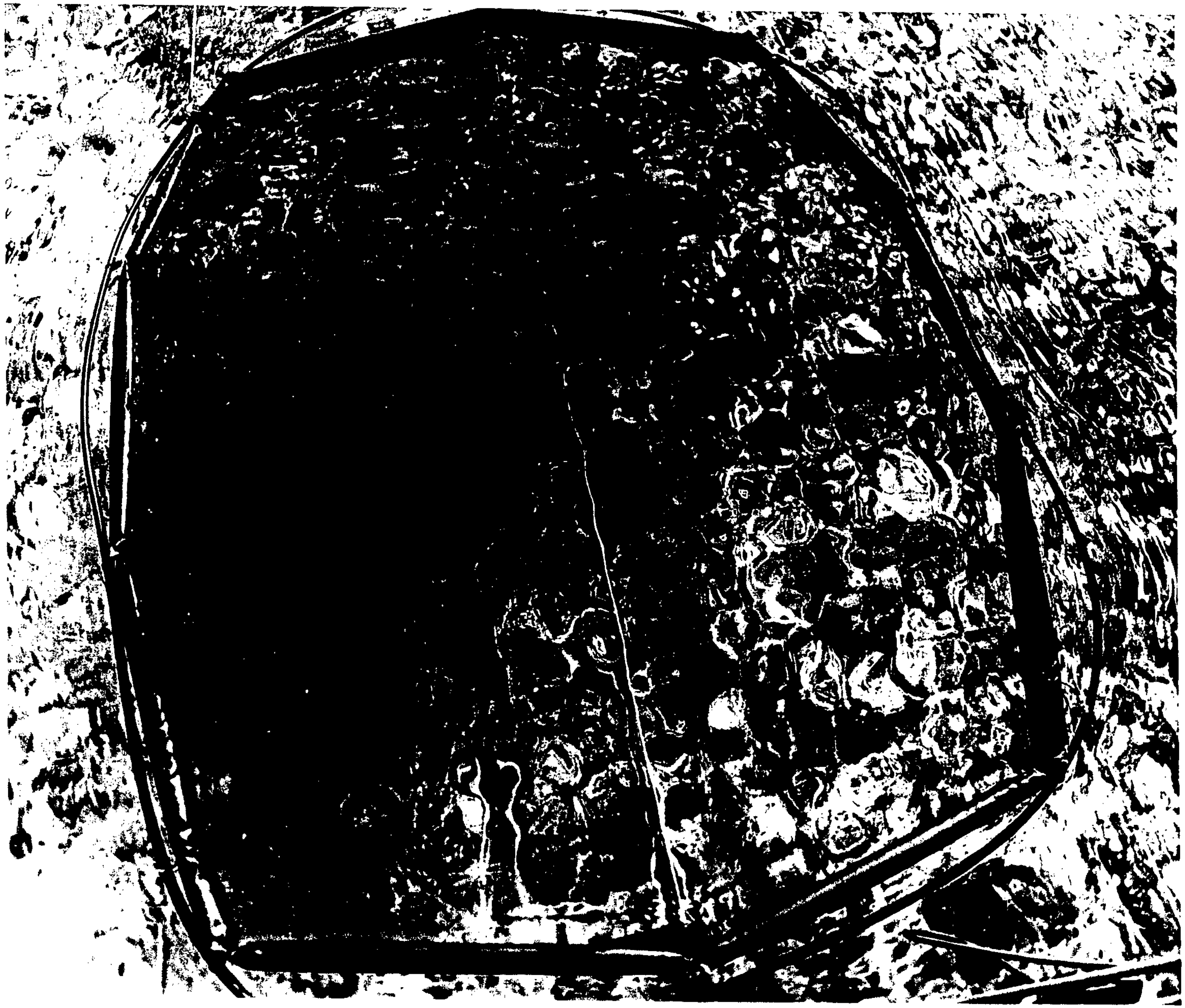

Figure 4-12 Photograph of 8.0 mm Diesel Oil Target Under Wave 1 Conditions, 13 October 1994

4.3.3 Analysis of 18 October Wave 1 Condition Measurements

Crude oil was measured on 18 October 1994 under wave 1 conditions. The T^B versus frequency plots for this data set are contained in Appendix E. Areas inside of the oil targets had been stirred as part of the calm-conditions measurements in an effort to measure tar-balls. Figure 4-13 illustrates the appearance of the 2.5 mm oil target with 40% intended surface area coverage. Note the swirly appearance between the oil and the water that was caused by the stirring, and the difference in surface texture between the disturbed and undisturbed oil. The higher percentage targets had areas of both undisturbed and disturbed oil, while the lower percentage targets only had areas of disturbed oil. The wave 1 condition did not break up the undisturbed oil.

All measurements of the 100% coverage pool (N182500A - E) were collected over the previously broken-up area; the results here are consistent with the results from the disturbed pool under calm wave conditions. The 10% intended coverage pool results (N182510A -C) show estimated thicknesses equivalent to a full coverage of 0.4 - 0.5 mm. The antenna beam for these measurements was only partially full, but it is difficult to see the difference between a 0.4 - 0.5 mm/full-coverage theoretical T^B curve and a 1.4 - 1.8 mm/small-percentage theoretical T^B curve. For the same reason, the 20% intended coverage pool results (N182520B, C) yielded estimates in the same 0.4 - 0.5 mm range if full coverage was assumed. The 40% intended coverage measurements (N182540A - C) had a higher antenna beam fill, and as can be seen, the results indicate a somewhat consistent thickness/percentage estimate. This is also true with the 80% coverage pool (N182580A - E). Measurements were collected using high percentage antenna beam fill, and the results again show a consistent thickness/percentage estimate.

Table 4-11. Results of 18 October 1994 Measurements of Crude Oil Under Wave 1 Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm) (% Fill)
N180000A	0.0					Reference
N180000B	0.0	0.050	0.025	0.000	0.025	0.025
N180000C	0.0	0.000	4.600	0.000	0.000	0.000
N182500A	3.2/95%	1.725	8.000	1.700	1.700	Emulsion
N182500B	3.2/95%	1.550	1.650	1.625	1.625	1.625
N182500C	3.2/95%	1.625	1.725	1.675	1.700	Emulsion
N182500D	3.2/95%	1.600	1.725	1.675	1.700	Emulsion
N182500E	3.2/95%	1.425	1.675	1.475	1.450	1.450
N182510A	Not Reported	0.450	1.225	3.500	0.450	0.450
N182510B	Not Reported	0.425	4.350	3.475	0.425	0.425
N182510C	Not Reported	0.525	0.875	3.675	0.525	0.525
N182520A	5.6/10%	0.700	1.150	0.725	0.700	Inconclusive
N182520B	5.6/10%	0.500	0.525	0.500	0.500	0.500
N182520C	5.6/10%	0.400	1.475	3.425	0.400	0.400
N182540A	2.3/40%	1.775	7.900	1.750	1.750	1.750
N182540B	2.3/40%	1.975	8.050	2.100	2.075	1.8 @ 85%
N182540C	2.3/40%	1.350	1.700	1.300	1.325	1.7 @ 90%
N182580A	3.2/75%	2.200	1.900	2.275	2.225	1.9 @ 80%
N182580B	3.2/75%	2.125	1.875	2.175	2.150	1.9 @ 85%
N182580C	3.2/75%	2.200	1.825	1.100	2.200	1.9 @ 80%
N182580D	3.2/75%	0.875	0.000	0.900	0.875	1.9 @ 60%
N182580E	3.2/75%	0.875	3.600	0.900	0.875	1.9 @ 60%

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

Figure 4-13 Photograph of Crude Oil 2.5 mm Oil Target with 40% Surface Area Coverage Under Wave 1 Conditions

4.3.4 Analysis of 19 October Wave 1 Condition Measurements

The measurement results for oil targets of unknown type and thickness, collected under wave 1 conditions on 19 October are shown in table 4-12. The T^B versus frequency plots for this data set are contained in Appendix G. The results shown for pools 2 and 3 (UNKW2A - C, UNKW3A - C) compare favorably with the results from the calm pool measurements. The two measurement sets from pool 1 (UNKWXA - C and UNKWXD - F) were taken from different areas in the oil target, and correlate well with the anticipated thickness and on-site comments that the oil appeared to have a thickness gradient across the pool.

The initial analysis results from pool 4 (UNKW4A - E) were mixed. The first three measurements were from the non-swirly area; one estimate (UNKW4A) shows a reasonably good agreement with the reported thickness, however, the next two yielded inconclusive results. The on-site notes recorded a partial antenna beam fill for these measurements, so taking this partial beam fill effect into account and using the reported thickness, the final result indicates a 1.7 mm estimate with an 80% - 85% beam fill would match both UNKW4B and UNKW4C. Revisiting the first measurement (UNKW4A), and using an 85% beam fill produced an excellent match. The final two measurements (UNKW4D - E) were taken near the swirly area; recall from the calm measurements that the results from the swirly area indicated an emulsion. The two results here are consistent and seem to indicate a thickness of 0.5 mm although visually (from the downlooking videotape) no difference in oil thickness or beam fill was observed between these two measurements and the first three measurements.

The results from oil target 5 (UNKW5A - E) seem consistent, but thinner than the reported thickness. The results from earlier measurements under calm conditions indicated an emulsion, so the comparison of results for this pool is difficult.

Table 4-12. Results of 19 October 1994 Measurements of Unknowns Under Wave 1 Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
UNKW1A	0.0					Reference
UNKW1B	0.0	0.000	4.275	0.000	0.000	0.000
UNKW1C	0.0	0.000	4.150	0.000	0.000	0.000
UNKWXA	0.84/80%	0.900	0.675	0.900	0.900	0.900
UNKWXB	0.84/80%	0.975	3.925	0.975	0.975	0.975
UNKWXC	0.84/80%	0.925	0.550	0.925	0.925	0.925
UNKWXD	0.84/80%	0.300	4.125	0.275	0.275	0.275
UNKWXE	0.84/80%	0.400	4.125	0.375	0.375	0.375
UNKWXF	0.84/80%	0.550	4.100	0.550	0.550	0.550
UNKW2A	2.6/100%	3.500	3.550	0.450	3.525	3.525
UNKW2B	2.6/100%	0.400	7.400	3.350	0.400	3.700
UNKW2C	2.6/100%	3.475	3.475	0.550	3.475	3.475
UNKW3A	2.0/100%	1.975	1.950	2.000	1.950	1.950
UNKW3B	2.0/100%	1.900	2.000	1.775	1.900	2.000
UNKW3C	2.0/100%	2.000	2.050	2.000	2.000	2.000
UNKW4A	1.7/60%	1.325	1.700	1.300	1.300	1.7 @ 85%
UNKW4B	1.7/60%	1.200	1.775	1.175	1.175	1.7 @ 80%
UNKW4C	1.7/60%	1.250	1.750	1.200	1.275	1.7 @ 80%
UNKW4D	1.7/60%	0.500	1.550	0.500	0.500	0.500
UNKW4E	1.7/60%	0.500	1.550	0.500	0.500	0.500
UNKW5A	2.5/100%	1.900	2.850	1.775	1.825	1.825
UNKW5B	2.5/100%	1.900	2.400	1.725	1.825	1.900
UNKW5C	2.5/100%	1.975	3.075	1.975	1.975	1.975
UNKW5D	2.5/100%	1.675	4.925	1.675	1.675	Emulsion
UNKW5F	2.5/100%	1.700	5.075	1.675	1.675	1.700

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

4.3.5 Analysis of 12 October Wave 2 Condition Measurements

The measurements taken on 12 October 1994 were part of the dry-run measurements. The T^B versus frequency plots for this data set are contained in Appendix C. The measurements reported in table 4-13 were collected using wave 2 conditions over a clear water pool and an 8.0 mm dyed diesel oil target that had been set out earlier in the day. The first two measurements over the oil target (G101280A, B) were collected as the waves began traversing through the pool; there was no previous agitation of the oil, and the liquid surface was somewhat flat. These two measurements indicate a reasonable thickness for that oil target. The remaining measurements were collected after the wave condition had fully developed. Additionally, there were air/water bubbles present on the surface of the oil. The results shown in table 4-13 indicate the FSR was unable to measure oil thickness under these conditions for this thickness of oil. It is believed that changes in the oil/water interface viewed by the antenna during the 12-second time interval required to complete a measurement sweep adversely affect the measurement of the radiometric signature; hence, an FSR with a faster data collection capability is needed.

Table 4-13. Results of 12 October 1994 Measurements of Diesel Oil Under Wave 2 Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
G101200A	0.0					Reference
G101200B	0.0	0.000	4.475	0.000	0.000	0.000
G101200C	0.0	0.100	1.425	0.025	0.075	0.075
G101280A	8.0/100%	6.775	3.300	0.925	6.775	6.775
G101280B	8.0/100%	6.800	3.325	0.850	6.800	6.800
G101280C	8.0/100%	1.125	4.925	1.100	1.100†	Inconclusive
G101280D	8.0/100%	2.225	3.100	2.100	2.150†	Inconclusive
G101280E	8.0/100%	0.975	7.400	2.425	0.975	0.975
G101280F	8.0/100%	1.050	4.200	1.050	1.050	1.050
G101280G	8.0/100%	1.775	7.250	1.800	1.775	1.775
G101280H	8.0/100%	1.650	7.725	1.700	1.675	1.675

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

† The plotted T^B versus frequency curve is different from the algorithm estimate. The reason for the difference is explained in the text of the appendix.

4.3.6 Analysis of 13 October Wave 2 Condition Measurements

The wave condition 2 measurements of 13 October used dyed diesel oil targets. The T^B versus frequency plots for this data set are contained in Appendix D. Table 4-14 contains the results of the wave 2 condition measurements. The measured data appears quite noisy for nearly all of this data set. It is believed that the noise is due to sun glint from the wave surfaces during the 12-second measurement interval. The additional noise in the measurements causes the smoothed data curve to have a more random shape characteristic than would otherwise be expected, and this shape characteristic is not correlated to the thickness of the oil film in a predictable way.

The only results that seem to match the calm condition measurements are the 0.5 mm oil target results (W101305A - F). The estimated thicknesses for the W101305A and W101305C measurements, 0.3 mm and 0.4 mm, seem to agree with the calm results while the W101305D and W101305E measurements tend to agree with the OHMSETT reported thicknesses. All of the other measurements in this data set show poor results. It is speculated that the motion of the oil targets caused by wave action during the 12-second measurement interval is the primary cause for the poor results.

Table 4-14. Results of 13 October 1994 Measurements of Diesel Oil Under Wave 2 Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
W101300A	0.0					Reference
W101300B	0.0	0.000	7.525	0.000	0.000	0.000
W101300C	0.0	0.000	4.450	0.000	0.000	0.000
W101305A	1.0/50%	0.300	7.575	0.300	0.300	0.300
W101305B	1.0/50%	0.450	7.825	3.200	0.450	Inconclusive
W101305C	1.0/50%	0.400	7.725	3.350	0.400	0.400
W101305D	1.0/50%	1.225	4.725	1.225	1.225	1.225
W101305E	1.0/50%	1.050	4.775	1.050	1.050	1.050
W101305F	1.0/50%	0.775	4.700	0.775	0.775	0.775
W101310A	1.4/70%	2.525	1.950	2.550	2.525†	Inconclusive
W101310B	1.4/70%	2.575	1.925	2.600	2.575†	Inconclusive
W101310C	1.4/70%	0.850	7.550	0.850	0.850	Inconclusive
W101320A	2.2/90%	1.000	7.750	1.000	1.000	Inconclusive
W101320B	2.2/90%	0.800	1.550	0.825	0.800	Inconclusive
W101320C	2.2/90%	0.775	7.700	0.775	0.775	0.775
W101320D	2.2/90%	0.800	7.550	0.825	0.800	0.800
W101320E	2.2/90%	2.150	1.975	2.225	2.175	2.0 or Inconclusive
W101320F	2.2/90%	1.050	4.250	1.050	1.050	1.050
W101330A	3.2/95%	1.025	1.275	1.025	1.025	1.025
W101330B	3.2/95%	1.000	4.675	1.000	1.000†	Inconclusive
W101330C	3.2/95%	1.000	1.600	1.000	1.000	1.000
W101330D	3.2/95%	0.950	4.750	0.975	0.950	0.950
W101330E	3.2/95%	0.850	4.650	0.850	0.850	0.850
W101330F	3.2/95%	2.275	1.900	2.350	2.300	Inconclusive
W101330G	3.2/95%	1.200	5.000	1.175	1.175	1.7 or Inconclusive
W101380A	8.0/100%	1.425	7.725	2.025	1.425	1.425
W101380B	8.0/100%	1.550	1.725	1.475	1.500	1.500

Table 4-14. Results of 13 October 1994 Measurements of Diesel Oil Under Wave 2 Conditions (cont.)

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla- tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
W101380C	8.0/100%	1.650	4.625	1.675	1.650	Emulsion
W101380D	8.0/100%	1.675	4.925	1.675	1.675	Emulsion w/ 4.9 shape

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

† The plotted T^B versus frequency curve is different from the algorithm estimate. The reason for the difference is explained in the text of the appendix.

4.3.7 Analysis of 18 October Wave 2 Condition Measurements

The results of the crude oil measurements under wave 2 conditions, shown in table 4-15, indicate that the FSR was unable to effectively estimate oil thickness under this wave condition. These results are consistent with the poor performance of the FSR under wave 1 conditions described in section 4.3.3. The T^B versus frequency plots for this data set are contained in Appendix E.

All of the oil targets showed visual indications of slight emulsification (light discoloration and a swirly look) and small bubbles were present on the surface of some of the higher-percentage fill targets. All of the measurements, except for the 10% (intended) fill targets (P182510A - C), had an antenna beam fill greater than 50%; the effect of emulsified oil measured with partial antenna beam fill is discussed in section 4.5. It is interesting to note that of the four measurements from which an oil thickness could be visually estimated (P182510B & C, P182520C, and P182580A), two of the measurements were from a low (approximately 30%) antenna beam fill, and of these two estimates, only one seems to agree well with the reported thickness. The remaining oil

targets all exhibited elevated T^B characteristics usually associated with emulsions and surface bubbles.

Table 4-15. Results of 18 October 1994 Measurements of Crude Oil Under Wave 2 Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
P180000A	0.0					Reference
P180000B	0.0	0.000	4.375	0.000	0.000	0.000
P180000C	0.0	0.000	1.625	0.000	0.000	0.000
P182500A	3.3/90%	1.675	1.700	1.675	1.675	Emulsion
P182500B	3.3/90%	1.700	1.675	1.675	1.675	Emulsion
P182500C	3.3/90%	1.700	1.875	1.675	1.675	Emulsion
P182510A	0.87/30%	0.000	7.425	0.000	0.000†	Inconclusive
P182510B	0.87/30%	3.575	7.450	0.475	3.575	3.700
P182510C	0.87/30%	0.775	4.600	0.800	0.775	0.775
P182520A	2.8/20%	1.700	4.950	1.675	1.675	1.675 or Emulsion
P182520B	2.8/20%	1.650	4.725	1.675	1.650	Emulsion
P182520C	2.8/20%	1.850	1.775	1.375	1.800	1.800
P182540A	1.5/75%	1.700	8.175	1.675	1.675	Emulsion
P182540B	1.5/75%	1.700	8.325	1.675	1.675	Emulsion
P182540C	1.5/75%	1.725	1.875	1.675	1.700	Emulsion
P182580A	3.0/80%	1.325	4.375	1.325	1.325	1.325
P182580B	3.0/80%	1.575	1.350	1.675	1.625	Emulsion
P182580C	3.0/80%	1.625	1.500	1.675	1.650	Emulsion

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

† The plotted T^B versus frequency curve is different from the algorithm estimate. The reason for the difference is explained in the text of the appendix.

4.3.8 Analysis of 19 October Wave 2 Condition Measurements

Table 4-16 lists the results of the unknown target measurements under wave 2 conditions. The T^B versus frequency plots for this data set are contained in Appendix G. The results here, compared to the wave 1 results in section 4.3.4 and the calm water results in section 4.2.8, seem to indicate that as wave conditions increase, the FSR becomes limited in its ability to estimate thicker oil films. The antenna beam was fully filled for all of the measurements in this data set. The results from pool 1 (UNKX1A - C), which was the thinnest of the oil pools, show that it was the only pool that had consistent measurements in this wave condition, and the results of the analysis compare favorably with both the OHMSETT-reported thickness and the thickness reported for calm and wave 1 conditions. One of the pool 2 measurements (UNKX2B) compares favorably with the calm measurement result, and the T^B curves of the other three estimates (about 0.7 mm) are quite similar in shape (except for an inflection point) to estimates in the 3.5 mm range.

All of the measurements from oil targets 4 and 5 yielded the high T^B and flat curve shape characteristic of foam/bubbles or emulsions. Pools 4 and 5 were both made from a mixture of diesel and waste oil. It is speculated that this mixture of diesel and waste oil may form bubbles or an emulsion with less agitation compared to either the unmixed diesel (pools 1 and 2) or a mix of diesel and crude (pool 3).

Table 4-16. Results of 19 October 1994 Measurements of Unknowns Under Wave 2 Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
UNKX6A	0.0					Reference
UNKX6B	0.0	0.000	3.925	0.000	0.000	0.000
UNKX6C	0.0	0.000	4.025	0.000	0.000	0.000
UNKX1A	0.84/80%	1.325	4.350	1.350	1.325	1.325
UNKX1B	0.84/80%	1.200	1.600	1.200	1.200	1.200
UNKX1C	0.84/80%	1.100	1.525	1.100	1.100	1.100
UNKX2A	2.7/95%	0.650	3.925	0.625	0.625	0.625
UNKX2B	2.7/95%	3.875	3.925	0.700	3.900	3.900
UNKX2C	2.7/95%	0.775	0.550	0.775	0.775	0.775
UNKX2D	2.7/95%	0.775	1.075	0.775	0.775	0.775
UNKX3A	2.0/100%	0.950	9.475	0.950	0.950	Inconclusive
UNKX3B	2.0/100%	0.875	2.025	2.500	0.875	Inconclusive
UNKX3C	2.0/100%	0.875	6.450	0.875	0.875	Inconclusive
UNKX4A	2.5/40%	1.650	4.675	1.675	1.650	Emulsion
UNKX4B	2.5/40%	1.675	1.700	1.675	1.675	Emulsion
UNKX4C	2.5/40%	1.675	1.775	1.675	1.675	Emulsion
UNKX4D	2.5/40%	1.700	1.700	1.675	1.700	Emulsion
UNKX5A	2.8/90%	1.650	3.425	1.675	1.650	Emulsion w/ 3.4 shape
UNKX5B	2.8/90%	1.750	9.500	1.675	1.700	Emulsion
UNKX5C	2.8/90%	1.750	2.925	1.700	1.725	Emulsion

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

4.4 CHOP CONDITIONS

In general, the FSR showed only limited success in the chop 1 measurements of diesel and unknown oils, and during the chop 2 measurements was not able to measure oil thickness. This is not a surprising result since the chop measurements were carried out after the wave condition 1 and 2 measurements, so the oil targets had been well agitated and in some cases waves had broken over the oil surface. Additionally, the movement of the containment booms seemed to add bubbles onto the surface of the oil. With the increased wave motion created by the chop conditions, the oil target surface deteriorated even more quickly.

4.4.1 Analysis of 14 October Chop 1 Condition Measurements

Measurements were collected 14 October 1994 using the dyed diesel oil targets under chop 1 wave conditions. These were the same oil targets that were used for the calm, wave 1, and wave 2 condition measurements completed on 13 October 1994. Table 4-17 documents the results of the oil estimation algorithm and the visual analysis of the data. The T^B versus frequency plots for this data set are contained in Appendix D.

Overall, this set of FSR data indicates that the instrument has difficulty measuring the characteristic sinusoidal variation of T^B versus frequency in these conditions. It is encouraging to note that even under the chop conditions the water measurements are within the expected values. There was some success in estimating the oil thickness for the 2.0 mm (intended thickness) oil target; the visual and algorithm results agree reasonably well with the OHMSETT-reported oil thickness for files I101420B and C. It is not well understood as to why the 3.0 mm measurements (I101430B - D) seem to match estimates on the order of 1.0 mm. It is suspected that the motion of the oil in the antenna footprint during the measurement interval may have caused some type of "temporal

averaging" effect. Recall that a 3.0 - 3.5 mm curve has a similar up-slope to a 1.0 mm curve over the Ka-band; the most prominent difference between the two estimates is that the thicker oil curve has a slight inflection point at the lower frequencies. Depending on the oil-water surface geometry, this characteristic may be missed by the FSR during its 12 second sweep interval.

Table 4-17. Results of 14 October 1994 Measurements of Diesel Oil Under Chop 1 Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
I101400A	0.0	0.000	4.200	0.000	0.000	0.000
I101400B	0.0	0.000	1.275	0.000	0.000	0.000
I101400C	0.0					Reference
I101420A	2.1/95%	2.575	2.350	2.575	2.575†	Inconclusive
I101420B	2.1/95%	2.575	2.625	2.575	2.575	2.575
I101420C	2.1/95%	2.675	2.550	2.650	2.650	2.650
I101430A	3.0/100%	0.825	4.350	0.825	0.825†	Inconclusive
I101430B	3.0/100%	0.900	1.350	0.900	0.900	0.900
I101430C	3.0/100%	1.100	7.700	1.100	1.100	1.100
I101430D	3.0/100%	1.075	1.400	1.075	1.075	1.075
I101430E	3.0/100%	1.650	4.775	1.675	1.650†	Emulsion
I101480A	8.0/100%	0.825	4.775	0.825	0.825†	Inconclusive
I101480B	8.0/100%	0.850	8.200	0.850	0.850	Inconclusive
I101480C	8.0/100%	0.875	8.975	0.900	0.875†	Inconclusive

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

† The plotted T^B versus frequency curve is different from the algorithm estimate. The reason for the difference is explained in the text of the appendix.

4.4.2 Analysis of 19 October Chop 1 Condition Measurements

Measurements of unknown oil type and thickness were conducted on 19 October under chop 1 conditions after the wave 1 and 2 condition measurements were complete. Table 4-18 contains the results of the oil thickness estimation algorithm as well as the visual analysis of the T^B measurement curves. The T^B versus frequency plots for this data set are contained in Appendix G.

The results of the measurements over unknown pool 1 (UNKY1A - D) indicate a good match to the reported thickness, and also match the calm condition measurements. The results from unknown pool 2 (UNKY2A - D) again are a good match to the calm condition measurements, although the measurements from this oil target are consistently higher than the reported thickness. The results from unknown pool 3 (UNKY3B - C) seem to match the calm measurement results. Results from pools 4 and 5 (UNKY4A - E, UNKY5A - C) show consistency within each data set, but the results do not match the calm measurement results or the oil target reported thickness. These two oil targets had previously yielded inconsistent results, possibly because of the mix with waste oil. In most cases the data are noisier than for calm conditions due to the influence of wave action on the measured T^B. Possible causes for the noise include sun glint, variation of the oil film thickness on the uneven dynamic wave surface, bubbles, or oil and water mixing effects.

Table 4-18. Results of 19 October 1994 Measurements of Unknowns Under Chop 1 Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
UNKY6A	0.0					Reference
UNKY6B	0.0	0.000	0.575	0.000	0.000	0.000
UNKY6C	0.0	0.000	4.175	0.000	0.000	0.000
UNKY1A	0.96/70%	0.800	3.950	0.775	0.775	0.775
UNKY1B	0.96/70%	0.925	0.975	0.925	0.925	0.925
UNKY1C	0.96/70%	1.000	0.225	1.000	1.000	1.000
UNKY1D	0.96/70%	0.950	4.500	0.950	0.950	0.950
UNKY2A	2.6/100%	0.675	3.525	0.675	0.675	3.500
UNKY2B	2.6/100%	0.675	3.425	0.675	0.675	3.400
UNKY2C	2.6/100%	4.075	3.925	0.800	4.000	4.000
UNKY2D	2.6/100%	0.700	3.650	0.700	0.700	3.600
UNKY3A	2.1/95%	1.850	6.250	1.700	1.775†	Inconclusive
UNKY3B	2.1/95%	1.800	9.300	1.675	1.725	1.800
UNKY3C	2.1/95%	1.825	9.175	1.700	1.750	1.750
UNKY4A	2.0/50%	1.100	0.550	1.100	1.100	1.100
UNKY4B	2.0/50%	1.125	4.425	1.125	1.125	1.125
UNKY4C	2.0/50%	1.075	1.325	1.075	1.075	1.075
UNKY4D	2.0/50%	0.000	4.050	0.000	0.000	0.000
UNKY4E	2.0/50%	0.250	4.300	0.200	0.225	0.225
UNKY5A	2.5/100%	1.825	3.000	1.700	1.750	1.750
UNKY5B	2.5/100%	1.950	3.025	1.950	1.950	1.950
UNKY5C	2.5/100%	2.025	3.125	2.100	2.050	Inconclusive

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

† The plotted T^B versus frequency curve is different from the algorithm estimate. The reason for the difference is explained in the text of the appendix.

4.4.3 Analysis of 14 October Chop 2 Condition Measurements

The results of the oil thickness estimation algorithm for the diesel oil measurements collected on 14 October are shown in table 4-19. The T^B versus frequency plots for this data set are contained in Appendix D. Figure 4-14 illustrates the appearance of the surface of the oil target in Chop 2 wave conditions. In this photo, the 8.0 mm oil target pool is shown. The oil appears dark in the photo and covers the entire containment area. The white areas have a foamy texture and are a result of the oil mixing with air and water as waves have broken over the surface of the target. Since the surface of all of the oil targets had an appearance similar to this, it is not surprising that all of the oil target measurements yielded flat T^B versus frequency signatures with high average T^B values.

The water background measurements were the last set of measurements taken for the diesel oil targets. The results show false positive indications of oil. It is suspected that there may be some oil intrusion into the water background target pool; however, this speculation is not confirmed by the site notes or down-looking videotape. Other possible causes for this false positive indication include sun glint effects or bubbles on the water surface.

Table 4-19. Results of 14 October 1994 Measurements of Diesel Oil Under Chop 2 Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
J101400A	0.0					Reference
J101400B	0.0	0.100	7.675	0.125	0.100	0.100
J101400C	0.0	0.275	4.275	0.275	0.275	0.275
J101400D	0.0	0.250	1.450	0.250	0.250	0.250
J101410A	1.25/80%	1.600	4.350	1.675	1.625†	Emulsion
J101410B	1.25/80%	1.675	4.850	1.675	1.675	Emulsion
J101410C	1.25/80%	1.700	1.750	1.675	1.700	Emulsion
J101420A	2.5/80%	1.675	4.375	1.675	1.675	Emulsion
J101420B	2.5/80%	1.700	4.800	1.675	1.675	Emulsion
J101420C	2.5/80%	1.700	7.800	1.675	1.675	Emulsion
J101430E	3.3/90%	1.650	4.775	1.650	1.650	Emulsion
J101480A	8.4/95%	1.700	1.775	1.675	1.750	Emulsion
J101480B	8.4/95%	1.675	1.725	1.675	1.675	Emulsion
J101480C	8.4/95%	1.675	4.950	1.675	1.675	Emulsion

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

† The plotted T^B versus frequency curve is different from the algorithm estimate. The reason for the difference is explained in the text of the appendix.

Figure 4-14 Photograph of 8.0 mm Diesel Oil Target Under Chop 2 Conditions, 14 October 1994

4.4.4 Analysis of 18 October Chop 2 Condition Measurements

The results of the crude oil measurements of 18 October under chop 2 conditions are shown in table 4-20. The T^B versus frequency plots for this data set are contained in Appendix E. By this point in the experiment, most of the oil targets had bubbles of water or air entrapped on the surface, had a more mottled texture on the surface, and were beginning to show signs of discoloration indicative of the oil mixing with water. The signature characteristic of foam/emulsion (T^B on the order of 250 K, with an overall flat slope) was recognized on measurements that had a high percentage of antenna footprint beam fill (90 - 100%). These measurements were collected over the 100% (Q182500 series), 80% (Q182580 series), and 40% (Q182540 series) coverage pools. The measurements over the 20% (Q182520 series) coverage pool, and the measurement of an oil target that had escaped the containment (Q18XXXX series), had a low percentage of antenna beam fill (20 - 30%). A lower percentage of antenna beam fill causes a proportionally lower T^B for the oil measurement because low T^B values from clean water are averaged with elevated T^B's from the oil/foam covered surface. A more detailed comparison of antenna beam fill effects for emulsion measurements is given in section 4.5.

Table 4-20. Results of 18 October 1994 Measurements of Crude Oil Under Chop 2 Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
Q180000A	0.0					Reference
Q180000B	0.0	0.000	0.000	0.000	0.000	0.000
Q180000C	0.0	0.000	4.050	0.000	0.000	0.000
Q182500A	3.0/100%	1.675	4.875	1.675	1.675	Emulsion
Q182500B	3.0/100%	1.675	7.925	1.675	1.675	Emulsion
Q182500C	3.0/100%	1.675	4.900	1.675	1.675	Emulsion
Q182520A	2.8/20%	3.650	3.675	3.675	3.675	3.675
Q182520B	2.8/20%	0.700	3.950	0.675	0.675	0.675
Q182520C	2.8/20%	0.450	7.325	0.450	0.450	0.450
Q182540A	2.8/40%	0.800	1.425	0.800	0.800	Inconclusive
Q182540B	2.8/40%	1.350	4.825	1.300	1.325	1.325
Q182540C	2.8/40%	1.650	3.925	1.675	1.650	Emulsion
Q182580A	2.7/90%	1.725	5.700	1.675	1.700†	Emulsion
Q182580B	2.7/90%	1.700	2.050	1.675	1.675†	Emulsion
Q182580C	2.7/90%	1.675	7.825	1.675	1.675	Emulsion
Q182580D	2.7/90%	1.675	7.825	1.675	1.675	Emulsion
Q182580E	2.7/90%	1.700	7.475	1.675	1.675	Emulsion
Q18XXXXA	Unknown	0.400	1.650	0.400	0.400	0.400
Q18XXXXB	Unknown	0.350	1.600	0.350	0.350	0.350
Q18XXXXC	Unknown	0.550	7.525	0.575	0.550	0.550

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

† The plotted T^B versus frequency curve is different from the algorithm estimate. The reason for the difference is explained in the text of the appendix.

4.4.5 Analysis of 19 October Chop 2 Condition Measurements

Table 4-21 documents the results of the 19 October 1994 measurements of unknown oil type and thickness under chop 2 conditions. The T^B versus frequency plots for this data set are contained in Appendix G. All of the oil thickness measurements in this data set show the same emulsion/foam signature characteristic. This result is not surprising since all of the oil target pools contained bubbles of entrapped water/air on the surface of the oil, the oil was becoming discolored as a result of mixing with water, and the antenna footprint was completely filled with this water/oil/air mixture.

The background water pool had been infiltrated with oil, and these small beads of oil moved through the antenna footprint during the measurement interval, so the FSR estimates of a thin oil film present in these pools is not an unexpected result.

Table 4-21. Results of 19 October 1994 Measurements of Unknowns Under Chop 2 Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
UNKZ6A	0.0					Reference
UNKZ6B	0.0	0.225	0.525	0.225	0.225	0.225
UNKZ6C	0.0	0.325	4.000	0.300	0.300	0.300
UNKZ1A	0.96/70%	1.700	8.875	1.675	1.675†	Emulsion
UNKZ1B	0.96/70%	1.725	1.900	1.675	1.700†	Emulsion
UNKZ1C	0.96/70%	1.700	5.400	1.675	1.675†	Emulsion
UNKZ2A	3.25/80%	1.700	1.825	1.675	1.675†	Emulsion
UNKZ2B	3.25/80%	1.700	5.125	1.675	1.675†	Emulsion
UNKZ2C	3.25/80%	1.700	5.050	1.675	1.675	Emulsion
UNKZ3A	2.5/80%	1.650	4.125	1.675	1.675	Emulsion w/ 4.1 shape
UNKZ3B	2.5/80%	1.650	4.350	1.675	1.650	Emulsion
UNKZ3C	2.5/80%	1.700	8.250	1.675	1.675†	Emulsion
UNKZ4A	2.0/50%	1.700	4.975	1.675	1.675†	Emulsion
UNKZ4B	2.0/50%	1.675	3.600	1.675	1.675†	Emulsion
UNKZ4C	2.0/50%	1.700	1.825	1.675	1.675	Emulsion
UNKZ5A	2.9/85%	1.700	3.650	1.675	1.675	Emulsion
UNKZ5B	2.9/85%	1.675	1.675	1.675	1.675	Emulsion
UNKZ5C	2.9/85%	1.700	7.450	1.675	1.675	Emulsion

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

† The plotted T^B versus frequency curve is different from the algorithm estimate. The reason for the difference is explained in the text of the appendix.

4.5 EMULSION MEASUREMENTS

Measurements of water/oil emulsions were completed on the afternoon of 14 October 1994. The T^B versus frequency plots for this data set are contained in Appendix F. Two different water/oil emulsion target types were used; one contained 40% water and 60% oil by volume (the filenames for this emulsion type contain a "40" in the third and fourth location), the second contained 20% water and 80% oil by volume (these filenames contain a "20" in the third and fourth location). When these oil/water emulsions were spread into the target pools, the emulsion tended to stay together near the containment booms instead of spreading uniformly throughout the pool. This is illustrated in figures 4-15, 4-16, and 4-17. Because the emulsion target remained compact, the FSR antenna footprint was not completely filled with the target substance. With the antenna beam only partially filled, the expected high average T^B for emulsion or foam (approximately 250 K) will not be measured. Rather, average T^B measured will be in direct proportion to the ratio of oil (or emulsion) to clean water visible within the antenna beam.

Table 4-22 documents the results of the 14 October 1994 emulsion measurements, made under calm conditions, for each of the methods used by the thickness estimation algorithm. Although the OHMSETT-reported data indicates that the oil was quite thick, the FSR was indicating thicknesses of less than 2.0 mm. None of the measured curves have a sinusoidal response indicative of uniformly thick oil. Additionally, none of the measured curves show the characteristic high brightness temperatures between 200 - 250 K which are normally associated with emulsion and/or foam. Some curves do, however, exhibit the expected flat T^B response across the Ka frequency band. Thus, it is assumed that the somewhat low proportion of emulsion within the antenna beam affected these measurements.

It is interesting to note a number of good matches between the measured, algorithm estimated, and visually estimated curves for the 20% water/80% oil emulsions (EM2010A - E, EM2020A - D). It is believed that the combination of a very low percentage of oil in the antenna beam along with the fact that emulsion measurements are usually somewhat flat caused the measured T^B to fall within the range of reasonable temperatures for uniform thin-oil measurements. Figures 4-15, 4-16, and 4-17 illustrate three of the oil targets that provided matches to the estimated curves. However, the FSR signature in these cases was not indicative of the actual oil or emulsion thickness.

The first two measurements of the 1.0 mm 20% oil target (EM2010A - B) were made over the large oil target shown in the bottom of figure 4-15. These two T^B curves show a very flat slope, with a mean temperature of approximately 155 K. The antenna beam fill for these measurements was approximately 25%. The last three measurements (EM2010C - E) have a lower beam fill (10%) and were collected over the oil target near the center of the pool to the right of the white dividing line. As expected, the mean temperature for the measurements is lower, with slope closer to that of a clean-water signature since the temperature contribution from the oil surface is less.

Figure 4-16 shows the 2.0 mm 20% water emulsion target. The first two measurements (EM2020A, B) made over this oil target had a 50% antenna beam fill, while the second two measurements (EM2020C, D) had a higher beam fill (nearly 90%). Again note that the mean temperature of the measurement is lower for the lower percentage beam fill.

Figure 4-17 illustrates the 2.0 mm 40% water emulsion target (EM4020A - E). The beam fill factor was approximately 50% for all of the measurements. It is not a surprise that all of the resulting curves have a similar appearance; the theoretical curves in the 1.7 mm range seem to be good estimates for this data set.

Table 4-22. Results of 14 October 1994 Measurements of Emulsions Under Calm Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
EM0000A	0.0	0.000	7.750	0.000	0.000	0.000
EM0000B	0.0					Reference
EM0000C	0.0	0.050	7.725	0.000	0.025	0.025
EM2010A	10/10%	0.425	4.300	3.300	0.425	0.425
EM2010B	10/10%	0.375	4.250	3.350	0.375	0.450
EM2010C	10/10%	0.175	1.425	0.150	0.150	0.150
EM2010D	10/10%	0.200	4.525	0.200	0.200	0.200
EM2010E	10/10%	0.225	1.475	0.225	0.225	0.225
EM2020A	7.5/20%	0.425	4.400	3.375	0.425	0.425
EM2020B	7.5/20%	0.800	4.375	0.825	0.800	0.800
EM2020C	7.5/20%	1.450	4.700	1.350	1.375	1.375
EM2020D	7.5/20%	1.600	4.800	1.825	1.700	1.600
EM4010A	10/10%	1.075	8.025	2.325	1.075	Inconclusive
EM4010B	10/10%	1.125	8.075	2.275	1.125†	Inconclusive
EM4010C	10/10%	1.175	8.075	2.225	1.175	Inconclusive
EM4010D	10/10%	1.050	4.625	1.050	1.050	Inconclusive
EM4010E	10/10%	0.650	1.600	0.675	0.650	0.650
EM4020A	20/10%	1.850	4.825	2.000	1.925	1.700
EM4020B	20/10%	1.175	4.750	1.150	1.150	Inconclusive
EM4020C	20/10%	1.200	4.700	1.175	1.175	Inconclusive
EM4020D	20/10%	1.950	4.875	2.100	2.025	1.800
EM4020E	20/10%	1.900	8.075	2.050	1.975	1.700

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

† The plotted T^B versus frequency curve is different from the algorithm estimate. The reason for the difference is explained in the text of the appendix.

Figure 4-15 Photograph of 20% Water-80% Oil Emulsion with 10% Surface Area Coverage Under Calm Conditions, 14 October 1994

Figure 4-16 Photograph of 20% Water-80% Oil Emulsion with 20% Surface Area Coverage Under Calm Conditions, 14 October 1994

Figure 4-17 Photograph of 40% Water-60% Oil Emulsion with 10% Surface Area Coverage Under Calm Conditions, 14 October 1994

Table 4-23 documents the results of the 14 October 1994 emulsion measurements, made under chop 2 wave conditions, for each of the methods used by the thickness estimation algorithm. The T^B versus frequency plots for this data set are contained in Appendix F. Similar to the measurements reported above, the antenna footprint was not completely filled with the oil targets. Again, similar results are seen in that no measurement resembled the expected emulsion response. However, some of the curves did exhibit the flatness seen in previous emulsion measurements. Thus, it is again assumed that the somewhat low proportion of emulsion within the antenna beam affected these measurements. There appeared to be more T^B measurement noise associated with the emulsion measurements during wave conditions versus calm conditions. This is not an unexpected result after analyzing the oil-on-water data; the wave and chop conditions produced sun-glinting and surface bubbles/foam.

Take, for example, the EW2005 measurements as an example to study the antenna beam fill effects. Figure 4-18 illustrates the appearance of the 0.5 mm 20% water/80% oil target. Note that even in the chop condition the emulsion is still clumped together, although it has formed into small blobs. The target surface has a somewhat lumpy texture. When this target was measured with a 60% beam fill (EW2005A, EW2005B), the results show a T^B curve that is flat, doesn't match well with theoretical T^B curves, but with a mean temperature that falls within the expected bounds for uniform oil of approximately 1.0 mm thickness. When measured with a lower antenna beam fill (EW2005C) of approximately 40%, the result is a good match to a theoretical T^B curve. With smaller beam fill percentages, the expected temperatures above the water background will be lower, and the amplitude variation of the brightness temperature will be reduced. This example illustrates both of these traits. However, it must be pointed out that the estimated thickness is not indicative of the actual oil or emulsion thickness under these circumstances.

Table 4-23. Results of 14 October 1994 Measurements of Emulsions Under Chop 2 Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correlation (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
EW0000A	0.0					Reference
EW0000B	0.0	0.000	4.550	0.000	0.000	0.000
EW0000C	0.0	0.125	4.475	0.100	0.100	0.000
EW2005A	10/5%	1.050	4.875	1.025	1.025	Inconclusive
EW2005B	10/5%	0.825	8.050	0.850	0.825	0.825
EW2005C	10/5%	0.450	1.175	0.450	0.450	0.450
EW4010A	20/5%	0.350	8.075	0.375	0.350	0.350
EW4020A	40/5%	0.850	4.600	0.850	0.850	0.850
EW4020B	40/5%	0.900	1.825	0.900	0.900	Inconclusive
EW4020C	40/5%	1.000	4.600	1.000	1.000	1.000
EW4020D	40/5%	0.850	4.550	0.875	0.850	Inconclusive
EW40XXA	20/5%	0.250	0.000	0.250	0.250	0.250

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

Figure 4-18 Photograph of 20% Water-80% Oil Emulsion with 5% Surface Area Coverage Under Chop 2 Conditions, 14 October 1994

4.6 "FLYING" MEASUREMENTS

The "flying" measurements were made with the OHMSETT main bridge moving over a calm pool to test the FSR response to measuring thicknesses over an area. The T^B versus frequency plots for this data set are contained in Appendix I. Shown in Table 4-24 are the results from the dyed diesel oil pools with the FSR moving at a velocity of 0.172 m/s. The algorithm estimates and the visual analysis results match the reported thicknesses well. In all cases, the antenna was positioned to collect a full beam fill measurement.

Table 4-24. Results of "Flying" Measurements of Diesel Oil Under Calm Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
H101400C	0.0					Reference
FLY2	2.1/95%	2.775	2.725	2.775	2.775	2.775
FLY3	3.0/100%	3.550	3.475	0.475	3.500	3.500
FLY8	8.0/100%	8.525	1.825	0.675	8.525	8.500

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

Shown in Table 4-25 are the results from the unknown thickness oil pools with the FSR moving at a velocity of 0.27 m/s. The FSR measurement was started after the antenna footprint entered the target pool, and the measurement was

complete before the antenna footprint swept over the containment boom. In this case, the algorithm estimates and visual analysis for the oil target in pool 2 (FLY2) match the thickness measured in pool under stationary, calm conditions. The results for pool 4 (FLY4) also seem to match the first three observations of oil target pool 4 during the stationary calm measurements, namely, that the T^B signature seems indicative of a foam or an emulsion, but in this case has a shape that matches a 5.2 mm oil estimate well. This could be an indication of a low percentage water emulsion at that thickness or the presence of some bubbles. It should be noted that the target pool contained a 50% mix of waste oil and diesel.

Table 4-25. Results of "Flying" Measurements of Unknowns Under Calm Conditions

File Name	Reported Thickness * (mm/ % cov.)	LMS Output (mm)	Correla-tion (mm)	Mean/ Slope (mm)	Algorithm Output (mm)	Visual Analysis (mm)
UNKREFB	0.0					Reference
FLYA4A	1.7/60%	1.750	5.225	1.675	1.700	5.200 or Emulsion
FLYA4B	1.7/60%	1.800	5.275	1.675	1.725	5.200 or Emulsion
FLYA2A	2.6/100%	3.250	3.250	3.125	3.250	3.250

* Reported thickness was provided by the OHMSETT facility staff. These values were computed by visually estimating the percentage of containment pool area covered by oil (% cov.) then dividing the known volume of oil by the estimated area covered to arrive at a thickness estimate. Uniform thickness within the covered surface was assumed, but this did not necessarily reflect the actual oil distribution.

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CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The FSR was used to measure oil films on water in an outdoor controlled experiment. Data were collected from a platform approximately 10 feet above the water surface under calm, uniform-wave, and choppy wave conditions using several different oil types. On site, the FSR operator was able to view (on the laptop computer screen) and comment on the quality of the measured versus theoretical fit for the radiometric brightness temperature plots. The initial conclusions based upon the on-site analysis was that the operator could use this on-screen plotting function to estimate oil thickness under calm conditions and some small wave conditions (wave 1) for uniform oil films; however, on-site estimates of oil thickness could not be made under the wave 2 and chop conditons. The post collection analysis results agree well with these on-site observations.

The estimation of thickness for patchy oil, emulsions, and oil films in chop conditions could not be performed by the operator on-site because the T^B versus frequency plots did not contain sufficient curvature detail to estimate thickness. In these cases, the fact that there was an elevated (above water) brightness temperature indicated the presence of oil; in some cases the analyst/operator could declare the presence of emulsion, foam or bubbles based on the characteristics of the plot (i.e., flat T^B versus frequency response with a mean of approximately 250 K). It was also found that, when clean water occupied a significant portion of the FSR antenna beam, emulsions and oil films with air/water bubbles entrapped on the surface often presented an overall flat T^B versus frequency response, with the mean temperature falling within the expected range for oil film thicknesses between a few tenths of a millimeter and 2.0 mm. Under these circumstances, the presence of oil could be detected, but the thickness data could be misleading.

A data collection using oil thicknesses unknown to the operator was performed. Under calm conditions, in 80% of the cases (4 pools out of a possible 5), the

operator was able to make a reasonable estimate of the oil thickness after three to four measurement sweeps. In one case, the resulting T^B versus frequency plots were somewhat ambiguous; the result could have been either a thickness of approximately 0.7 mm or a thickness of approximately 3.3 mm. Many more measurement sweeps were required to identify the actual oil thickness. During the post-collection analysis of these ambiguous targets, the oil thickness estimation algorithm assisted in correctly identifying the actual oil thickness.

The results of all the measurements taken during the wave 1 conditions seem to indicate that the FSR may be capable of measuring thickness, but as wave conditions increase, the variation (undulation) of the oil/water surface over time causes measurement inconsistencies. As long as the oil has not begun to mix with water, the radiometric brightness temperature plots seem to remain within the temperature range expected for oil-on-water; however, the curve shape is sometimes not recognizable as a specific thickness. A shorter measurement interval is needed in these dynamic situations which could create an instantaneous "snapshot" of the surface. To this end, the existing single-channel FSR instrument parameters could be used in the design of a multichannel radiometric system that simultaneously observes the entire 26 - 40 GHz (Ka) band.

The results of all the measurements taken during the wave 2 and chop conditions show that the FSR is not capable of measuring oil thickness under these conditions. The T^B curves tend to exhibit a noisier characteristic leading to a very high percentage of inconclusive estimates. Additionally, the mixing of water and air (through wave agitation) into the oil surface creates surface bubbles and a water/oil emulsion. The resulting T^B curves for these mixtures fully filling the antenna beam create a recognizable characteristic signature that is much warmer than the expected oil-on-water T^B. However, with partial beam fill effects, the T^B curves exhibit a flat characteristic that does not match the theoretical predictions. This will be a limiting factor in the use of the FSR because the phenomenology of the surface is different than the underlying assumptions, i.e. that the area under investigation is a flat, clear (meaning no other inclusions) film of oil-on-water.

During the post-collection data analysis, a simple oil thickness estimation algorithm was developed. This algorithm begins by creating a smoothed curve to fit the measured data points. Visually, this smoothed curve is much easier to compare against the family of theoretical radiometric brightness temperature curves. The algorithm compares this smoothed curve against a set of theoretical predictions for oil thicknesses from 0.0 mm to 10.0 mm using a least-mean-squares analysis, correlation (curve shape matching), and a mean/slope comparison (mean/slope is only good for thicknesses from 0.0 mm to 4.0 mm). The resulting output of these three methods are compared, and an estimated thickness is declared. The analyst has the opportunity to override the algorithm-declared estimate in cases where it is obvious that the estimate is incorrect. An additional feature allows the analyst to generate theoretical estimates of cases where the antenna footprint is not completely filled with oil. This algorithm shows some promise although significantly more effort is needed to develop a truly robust and operationally-useful algorithm that can reliably estimate oil thickness with minimal human intervention.

The estimation of the thinner oil films (i.e., thicknesses under 2.0 mm), even under calm conditions, was difficult because the T^B versus frequency response of the oil at these thicknesses is virtually a straight line. Although the mean/slope method of analysis leads to reasonable results, thicknesses between 0.0 mm and 0.5 mm seem to be extremely sensitive to changes in the background water brightness temperature measurements. In cases of partial antenna beam fill, the problem is compounded by the fact that theoretical T^B curves for a mix of clean water and thicker oil (e.g., 1.4 - 1.8 mm at 40% surface coverage) very closely match the T^B curves for thinner oils (0.4 - 0.6 mm with full surface coverage). In order to measure thin films of oil, additional FSR bandwidth is necessary so that other curve traits can be exploited. Based on atmospheric absorption, the next logical frequency band for instrument development is in the 75 - 110 GHz band, otherwise referred to as W-band.

In calm conditions with uniform oil layers, when the FSR signature appeared to provide an unambiguous oil thickness estimate, the estimate did not always agree with the OHMSETT reported value. These somewhat conflicting results highlight the difficulty of providing accurate surface truth information for oil slick thickness measurements. The OHMSETT reported thickness was computed

using the known volume of oil dispensed into the target area, then visually estimating the surface area coverage of each oil target. It is postulated that the OHMSETT estimate of oil thickness was usually good to within ± 10%. However, factors such as evaporation, oil "herding" even in a light breeze, and occasional large oil dispensing errors may have contributed to the conflicting results. Future FSR tests would benefit from closer attention to these factors during data collection and analysis.

The current method of calibrating the radiometer involves using the measured temperature differential between a cold source and a hot source. The hot source is a terminated waveguide load at ambient temperature, while the cold source is a piece of microwave absorbent material, cooled by liquid nitrogen, which is placed in front of the FSR antenna. The logistics of obtaining liquid nitrogen, although it is a readily available resource, and the precautions needed while using it make this calibration method somewhat cumbersome. Calibrating an airborne FSR this way would be highly impractical. A new calibration method needs to be developed if a viable airborne FSR is to be produced.

5.2 RECOMMENDATIONS

Two sensor upgrades would mitigate two notable shortcomings of the present FSR system, namely, (1) problems measuring oil thicknesses in wave conditions, and (2) measurement of thin films. These upgrades, described in detail in the following paragraphs, are (1) a faster measurement interval (2) a larger system bandwidth.

A multichannel 26 - 40 GHz radiometer that uses the system parameters of the existing FSR would address the problems of the oil surface movement during measurements. This instrument would implement a short dwell time (less than 1 second) measurement by using multiple receiver channels in parallel. After system development and laboratory testing, an OHMSETT test, similar in scope to this test would need to be conducted to baseline the radiometer performance under wave conditions.

In order to measure and estimate thinner oil films, a 75 - 110 GHz FSR is indicated. Such a W-band FSR should start as a proof-of-concept instrument

used to study phenomenology at this higher frequency band. With a single channel instrument, it would be easy (and relatively inexpensive) to optimize the system parameters in a manner similar to the Ka-band instrument development. If the development and testing of the W-band instrument is shown to be successful in a laboratory environment, OHMSETT testing could follow. These tests would emphasize measurement of thinner (less than 4.0 mm) oil films because it is in this thickness regime that measurement ambiguity exists when a Ka-band FSR is used alone.

It should be noted that even with a wideband, multichanel radiometric system (Ka-band only or even a dual Ka/W-band instrument), this technology has risk. In particular, (1) measurements of oil-on-water under partial antenna beam fill conditions will still be difficult to analyze, (2) the effect of sun glinting from the wave surfaces will cause unusually high brightness temperature measurements, requiring tactics to reduce this effect (e.g., flight direction, time of day, and planning observations relative to sun angle), and (3) measurements of emulsions and oil with bubbles on the surface will lead to flat T^B curves with the result that the thickness estimate will be inconclusive, indicating only the presence of oil in this condition.

In any event, visual comparison of a smoothed measurement curve (instead of the noisy measured data) against a theoretical prediction during on-site testing would be a valuable quality control check of the data in "real-time". Therefore the inclusion of a smoothed T^B versus frequency curve into the laptop computer software is recommended. Since the theoretical response of oil-on-water is a quasi-sinusoidal function, the use of a third degree polynomial may not be optimal for fitting the smoothed curve to the measured data points; the use of a sinusoidal function for curve fitting should be pursued.

If an operational instrument is to be deployed in the field, it should be capable of reliably estimating oil thickness without extensive operator intervention. With this in mind, robust algorithms that can estimate the oil thickness from FSR data need to be developed and tested. This should involve both "fine-tuning" of the existing algorithm and investigation of new methods. Existing data from calm-water measurements made at OHMSETT and possible future data from Ka-band multichannel radiometer tests at OHMSETT could be used for algorithm

training and testing. Finally, the algorithm will need to be incorporated into the upgraded FSR system control software prior to any airborne integration.

The inclusion of hardware to internally calibrate the radiometer is already under investigation. A terminated load at the waveguide mixer could be replaced by a noise source. The noise source would be controlled to create two known brightness temperatures. With the two known temperatures, the instrument could be calibrated using the same method already in use. This effort also would also need to be completed and validated prior to airborne integration.

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APPENDIX A

BRIGHTNESS TEMPERATURE VERSUS FREQUENCY PLOTS FROM FSR VALIDATION TESTS

The frequency scanning radiometer was tested after the receiver hardware modification for OHMSETT tests. Validation tests were conducted on 5 and 6 October 1994 atop the Lincoln Laboratory B-Building roof. Measurements were conducted using the laboratory-constructed calibrated test tank, with 10W-30 motor oil thicknesses ranging from 0.0 mm to 8.0 mm in steps of 0.5 mm. Additionally, the receiver noise temperature of the modified FSR was compared to the receiver noise temperature of the FSR measured during the testing described in reference 1.

The file naming convention used for data files was cttxmmdd.DAT, where c is a letter identifier for the test session (K = 5 Oct. 94, M = 6 Oct. 94), tt is the thickness in tenths of a millimeter, x is the pass identifier, mm is the month (October = 10), and dd is the day. Thus K25B1005.DAT was the second pass collected on 5 October 1994 using an oil thickness of 2.5 mm.

The plots shown in this appendix are radiometric brightness temperature (T^B), expressed in Kelvin (K), as measured by the FSR, versus the measurement frequency in GHz. Under the current FSR software configuration, sixteen equally spaced points between 26.5 GHz and 40.0 GHz are sampled, with each sample period somewhat less than one second. These sixteen points are plotted as 'measured' points. For each data set, the oil thickness estimation algorithm, described in Chapter 4, is used to estimate an oil film thickness. This algorithm-derived estimate is displayed with the smoothed curve and the declared result plotted over the actual measured points. The data analyst can then either choose to accept the algorithm estimate, or manually select a curve that may be a better fit to the measured data.

A visual comparison of the measured curves versus the apparent best fit theoretical prediction produced the results in Table A-1. The aggregate results yielded by the oil thickness estimation algorithm are shown in Table A-2. Tables

A-3 through A-5 show the raw results of each curve-fitting method used in the algorithm. Figures A-1 through A-66 show the raw FSR measurements plotted with the smoothed raw data curve and the theoretical T^B versus frequency curve for the best fit visual analysis estimate of oil thickness. All of the T^B versus frequency curves plotted in this appendix use the "A Ref" as the background water measurement. Figure A-67 is a comparison of the receiver noise temperatures before and after receiver modifications were performed to support the OHMSETT test.

The darkened cells in Table A-1 indicate thicknesses that were significantly different from the actual known oil thickness. The darkened cells in Tables A-2 through A-5 indicate thicknesses that were significantly different from the visual analysis results.

Table A-1

Visual Analysis Results of Oil Thickness For FSR Validation Tests

Actual Thickness (mm)	5 Oct. 94 Pass 1 (mm) A Ref	5 Oct. 94 Pass 2 (mm) A Ref	5 Oct. 94 Pass 1 (mm) B Ref	5 Oct. 94 Pass 2 (mm) B Ref	6 Oct. 94 Pass 1 (mm) Note 1	6 Oct. 94 Pass 2 (mm) Note 1
0.5	0.0	0.0	0.375	0.450	0.325	0.500
1.0	0.625	0.625	0.850	0.850	0.750	0.775
1.5	1.025	1.050	1.375	1.400	1.900	1.900
2.0	1.900	1.900	1.825	1.800	2.000	2.200
2.5	2.250	2.250	2.250	2.250	2.725	2.775
3.0	2.975	2.975	2.650	2.650	3.125	3.200
3.5	3.300	3.325	3.325	3.325	3.625	3.625
4.0	3.800	3.800	3.850	3.825	4.275	4.175
4.5	4.200	4.225	4.375	4.350	4.575	4.550
5.0	4.800	4.800	4.825	4.825	5.175	5.050
5.5	5.250	5.250	5.225	5.225	5.400	5.450
6.0	5.700	5.750	5.650	5.775	6.075	6.025
6.5 (Note 2)	6.300	6.325	6.300	6.325	6.500	6.500
7.0	6.775	6.750	6.800	6.800	6.900	6.850
7.5	7.175	7.225	7.250	7.250	7.350	7.325
8.0	7.775	7.775	7.775	7.775	7.925	7.900

Note 1 - Water measurements were taken but not recorded for 6 Oct. 94. Theoretical water background T^B measurements were assumed to be the same as 5 Oct. 94.

Note 2 - Although the files for 5 Oct. 94 are labeled as 6.6 mm, they were actually 6.5 mm oil thickness.

Table A-2

Results of Oil Thickness Estimation Algorithm For FSR Validation Tests

Actual Thickness (mm)	5 Oct. 94 Pass 1 (mm) A Ref	5 Oct. 94 Pass 2 (mm) A Ref	5 Oct. 94 Pass 1 (mm) B Ref	5 Oct. 94 Pass 2 (mm) B Ref	6 Oct. 94 Pass 1 (mm) Note 1	6 Oct. 94 Pass 2 (mm) Note 1
0.5	0.0*	0.0*	0.375	0.450	0.325	0.500
1.0	0.625	0.625	0.850	0.850	0.750	0.775
1.5	1.025	1.050	1.375	1.400	2.200	2.175
2.0	2.200	2.200	1.825	1.800	2.200	2.200
2.5	2.525	2.525	2.250	2.250	2.725	2.775
3.0	2.975	2.975	2.650	2.650	3.125	3.200
3.5	3.300	3.300	0.600*	0.575	3.600	3.625
4.0	3.650	3.650	3.850	3.825	4.275	4.175
4.5	4.200	4.175	4.375	4.350	4.575	4.550
5.0	4.800	4.800	4.825	4.825	5.200	5.050
5.5	5.300	5.275	5.225	5.200	5.400	5.450
6.0	5.750	5.750	5.650	5.650	6.075	6.025
6.5 (Note 2)	6.300	6.325	2.400*	2.400*	6.425	6.400
7.0	6.775	6.750	6.800	6.800	6.850	6.875
7.5	7.225	7.225	7.250	7.250	7.350	7.325
8.0	7.775	7.775	7.775	7.775	7.925	7.900

Note 1 - Water measurements were taken but not recorded for 6 Oct. 94. Theoretical water background T^B measurements were assumed to be the same as 5 Oct. 94.

Note 2 - Although the files for 5 Oct. 94 are labeled as 6.6 mm, they were actually 6.5 mm oil thickness.

* Indicates algorithm derived estimates that are very different from the actual thickness. The A Water Reference of 5 Oct. seemed warmer than the B reference; note that with the warmer reference, thin oil layers are estimated as lower values. Correlation only results give estimates of 3.375 mm (5 Oct. Pass 1 B Ref, 3.5 mm), 6.300/6.325 mm (5 Oct. Pass 1 & 2, B Ref, 6.5 mm), and 1.900/1.875 mm (6 Oct. Pass 1 & 2, 1.5 mm).

Table A-3

Results of Oil Thickness Estimates Using Only LMS For FSR Validation Tests

Actual Thickness (mm)	5 Oct. 94 Pass 1 (mm) A Ref	5 Oct. 94 Pass 2 (mm) A Ref	5 Oct. 94 Pass 1 (mm) B Ref	5 Oct. 94 Pass 2 (mm) B Ref	6 Oct. 94 Pass 1 (mm) Note 1	6 Oct. 94 Pass 2 (mm) Note 1
0.5	0.000	0.000	0.375	0.450	0.325	0.500
1.0	0.625	0.625	0.850	0.850	0.750	0.775
1.5	1.025	1.050	1.375	1.375	2.175	2.150
2.0	2.175	2.150	1.800	1.800	2.200	2.200
2.5	2.525	2.525	2.250	2.250	2.725	2.825
3.0	2.975	2.975	2.675	2.650	3.125	3.200
3.5	3.300	3.300	0.600	0.575	3.575	3.600
4.0	3.675	3.675	3.925	3.925	4.275	4.200
4.5	4.175	4.150	4.500	4.475	4.575	4.550
5.0	4.775	4.800	4.850	4.850	5.200	5.050
5.5	5.300	5.275	5.225	5.200	5.450	5.500
6.0	5.800	5.800	5.575	5.575	6.100	6.050
6.5 (Note 2)	6.325	6.350	2.425	2.425	6.425	6.400
7.0	6.775	6.750	6.800	6.800	6.850	6.875
7.5	7.200	7.225	7.275	7.300	7.350	7.325
8.0	7.800	7.775	7.775	7.775	7.925	7.925

Note 1 - Water measurements were taken but not recorded for 6 Oct. 94. Theoretical water background T^B measurements were assumed to be the same as 5 Oct. 94.

Note 2 - Although the files for 5 Oct. 94 are labeled as 6.6 mm, they were actually 6.5 mm oil thicknesses

Table A-4

Results of Oil Thickness Estimates Using Only Correlation For FSR Validation Tests

Actual Thickness (mm)	5 Oct. 94 Pass 1 (mm) A Ref	5 Oct. 94 Pass 2 (mm) A Ref	5 Oct. 94 Pass 1 (mm) B Ref	5 Oct. 94 Pass 2 (mm) B Ref	6 Oct. 94 Pass 1 (mm) Note 1	6 Oct. 94 Pass 2 (mm) Note 1
0.5	4.425	4.375	4.425	4.375	7.775	7.775
1.0	1.025	1.225	1.025	1.225	1.525	1.225
1.5	4.475	4.500	4.475	4.500	1.900	1.875
2.0	1.850	1.825	1.850	1.825	2.050	2.075
2.5	2.250	2.250	2.250	2.250	2.550	2.775
3.0	2.775	2.775	2.775	2.775	3.150	3.225
3.5	3.325	3.325	3.325	3.325	3.625	3.675
4.0	3.800	3.825	3.800	3.825	4.275	4.150
4.5	4.250	4.225	4.250	4.225	4.575	4.575
5.0	4.825	4.825	4.825	4.825	1.825	5.050
5.5	1.850	1.850	1.850	1.850	5.375	5.425
6.0	5.725	5.725	5.725	5.725	6.050	6.000
6.5 (Note 2)	6.300	6.325	6.300	6.325	3.125	3.100
7.0	3.300	3.300	3.300	3.300	3.325	3.350
7.5	7.250	7.250	7.250	7.250	7.375	7.325
8.0	7.775	7.775	7.775	7.775	7.925	7.900

Note 1 - Water measurements were taken but not recorded for 6 Oct. 94. Theoretical water background T^B measurements were assumed to be the same as 5 Oct. 94.

Note 2 - Although the files for 5 Oct. 94 are labeled as 6.6 mm, they were actually 6.5 mm oil thicknesses

Table A-5

Results of Oil Thickness Estimates Using Only Mean/Slope For FSR Validation Tests (Note 1)

Actual Thickness (mm)	5 Oct. 94 Pass 1 (mm) A Ref	5 Oct. 94 Pass 2 (mm) A Ref	5 Oct. 94 Pass 1 (mm) B Ref	5 Oct. 94 Pass 2 (mm) B Ref	6 Oct. 94 Pass 1 (mm) Note 2	6 Oct. 94 Pass 2 (mm) Note 2
0.5	0.000	0.000	0.375	0.475	0.350	0.500
1.0	0.625	0.625	0.850	0.850	0.775	0.800
1.5	1.025	1.050	1.400	1.425	2.250	2.225
2.0	2.250	2.250	1.725	1.700	2.225	2.225
2.5	2.550	2.550	2.225	2.225	2.750	2.800
3.0	3.000	2.975	2.650	2.650	3.025	3.100
3.5	0.350	0.325	0.625	0.600	0.525	0.525
4.0	3.625	3.650	0.725	0.750	0.875	0.825
4.5	0.800	0.800	1.050	1.050	0.975	0.950
5.0	0.950	0.950	1.250	1.275	1.075	0.975
5.5	0.925	0.925	2.175	2.150	2.475	2.500
6.0	2.600	2.575	2.275	2.275	2.650	2.650
6.5	2.675	2.675	2.400	2.375	2.725	2.725
7.0	0.725	0.700	0.975	0.9500	0.775	0.750
7.5	0.750	0.750	1.000	1.000	0.825	0.825
8.0	2.675	2.675	2.375	2.375	2.600	2.600

Note 1 - The mean/slope method will only estimate oil thicknesses up to 4.0 mm.

Note 2 - Water measurements were taken but not recorded for 6 Oct. 94. Theoretical water background T^B measurements were assumed to be the same as 5 Oct. 94.

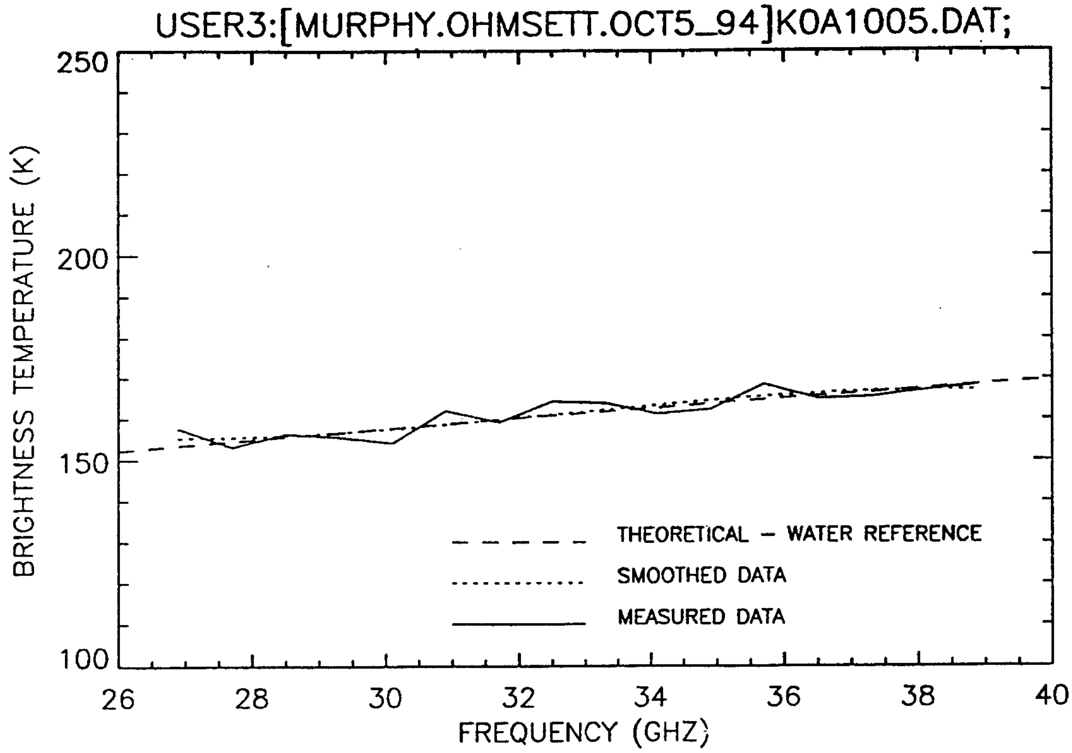

Figure A-1 T^B Versus Frequency Plot for Background Water, 5 October 1994, Pass 1

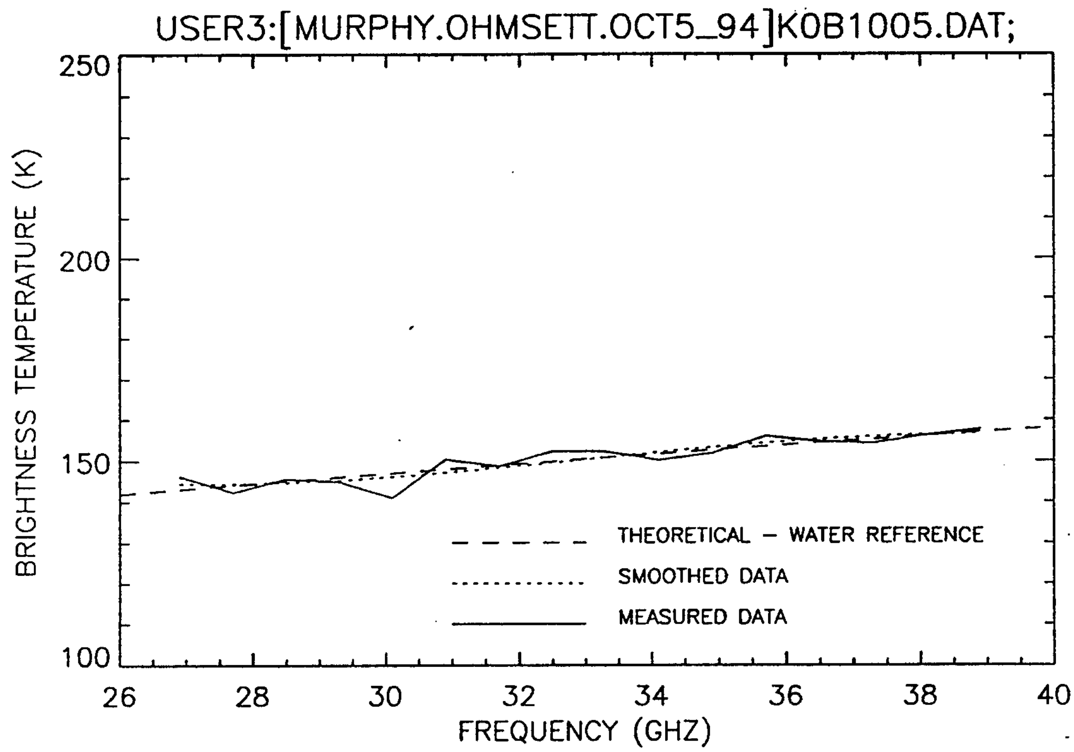

Figure A-2 T^B Versus Frequency Plot for Background Water, 5 October 1994, Pass 2

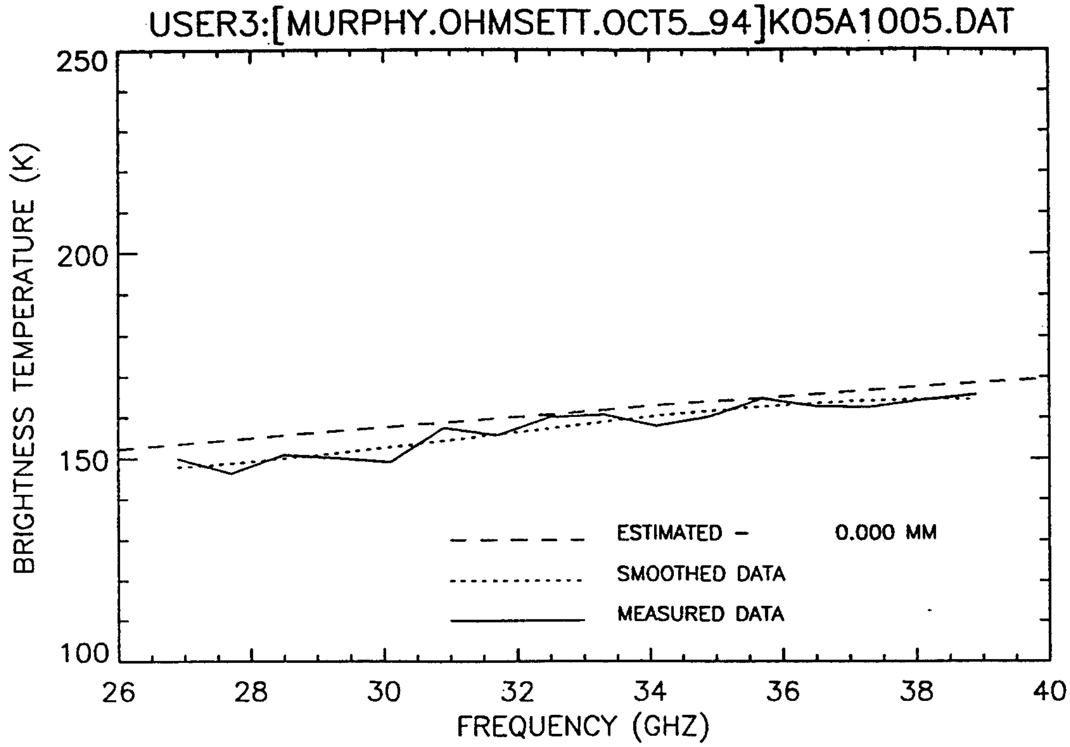

Figure A-3 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, 5 October 1994, Pass 1

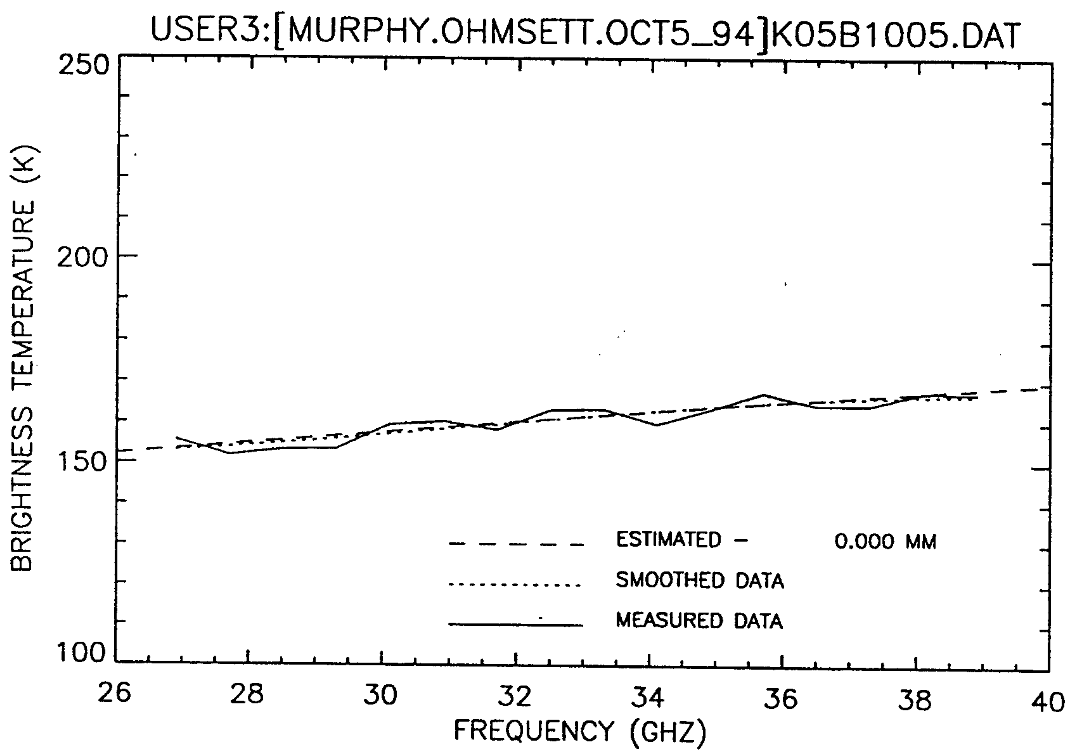

Figure A-4 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, 5 October 1994, Pass 2

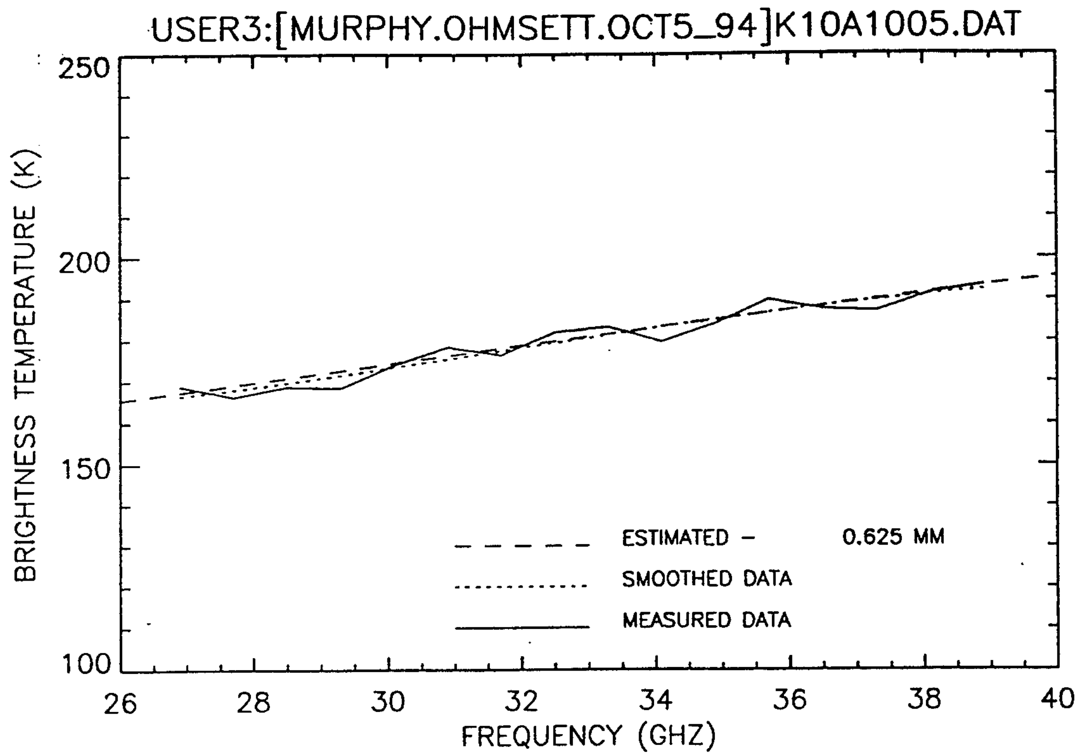

Figure A-5 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, 5 October 1994, Pass 1

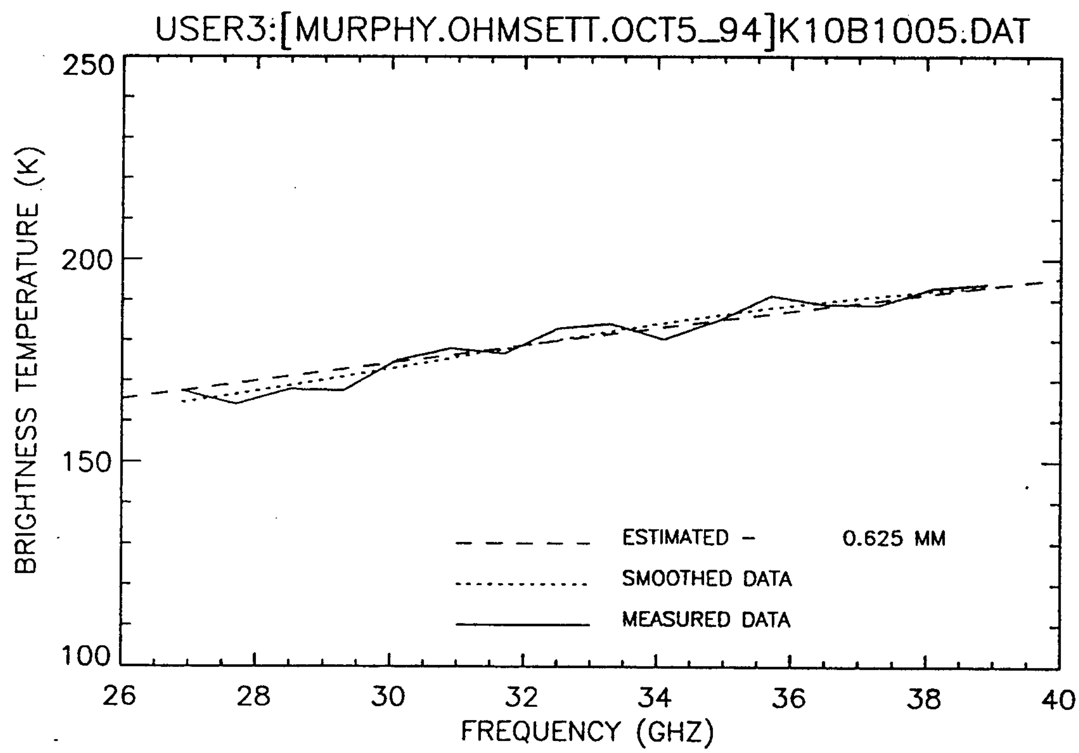

Figure A-6 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, 5 October 1994, Pass 2

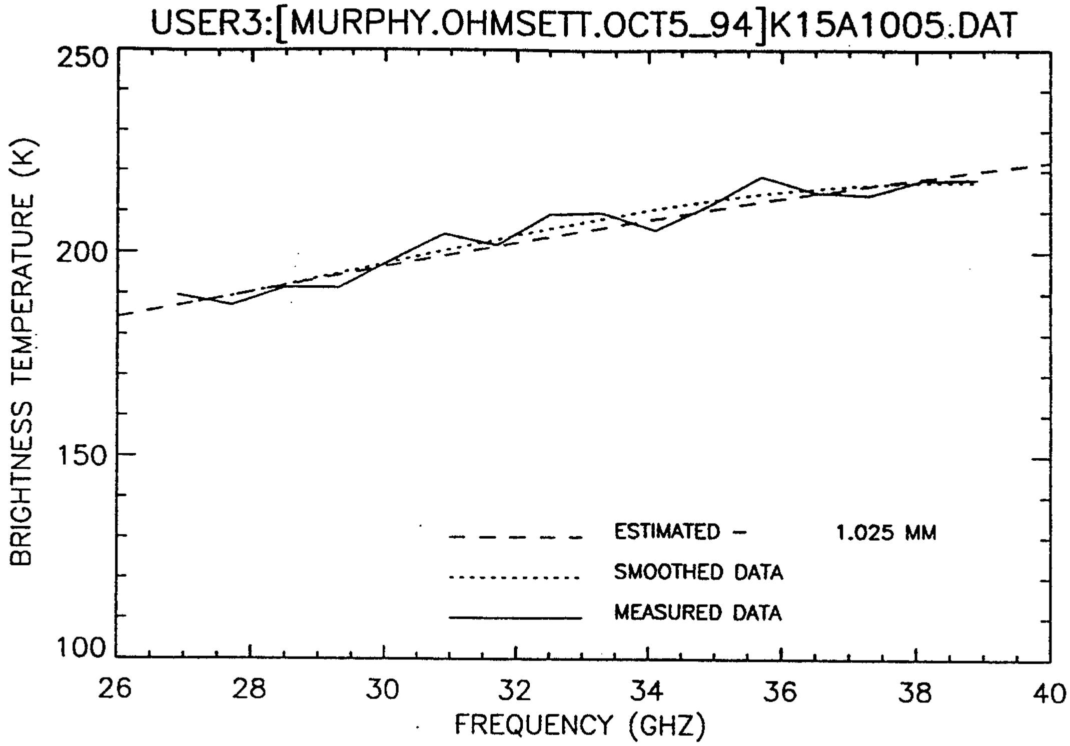

Figure A-7 T^B Versus Frequency Plot for 1.5 mm Uniform Oil Thickness, 5 October 1994, Pass 1

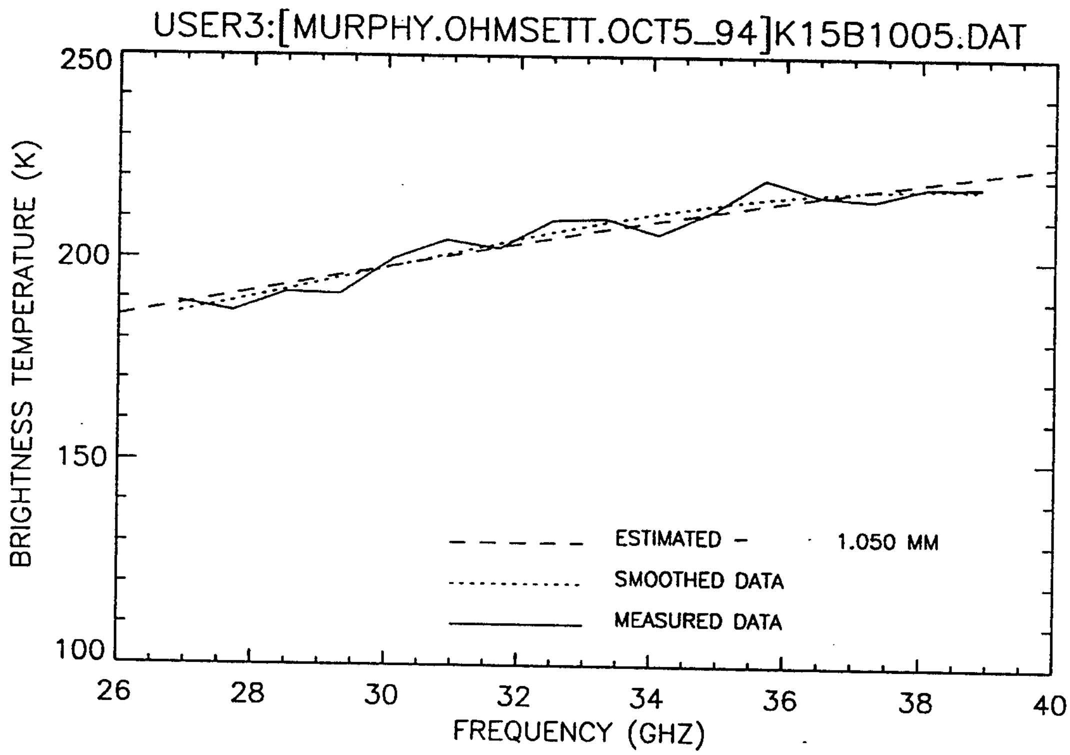

Figure A-8 T^B Versus Frequency Plot for 1.5 mm Uniform Oil Thickness, 5 October 1994, Pass 2

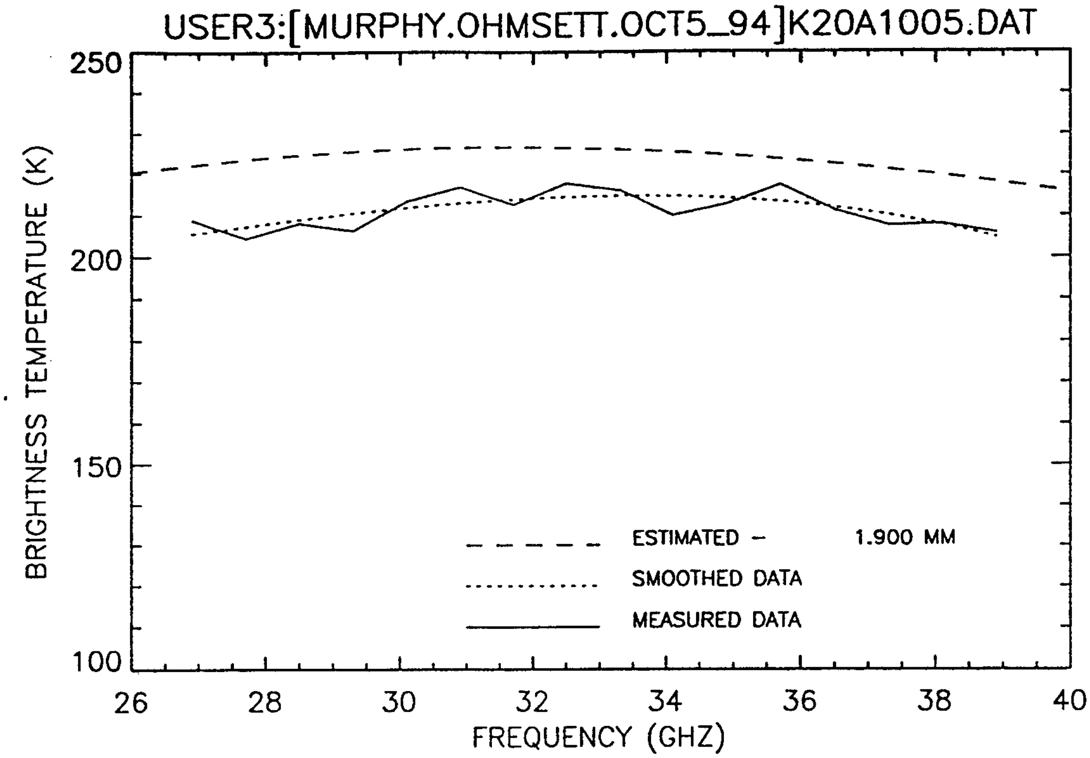

Figure A-9 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, 5 October 1994, Pass 1

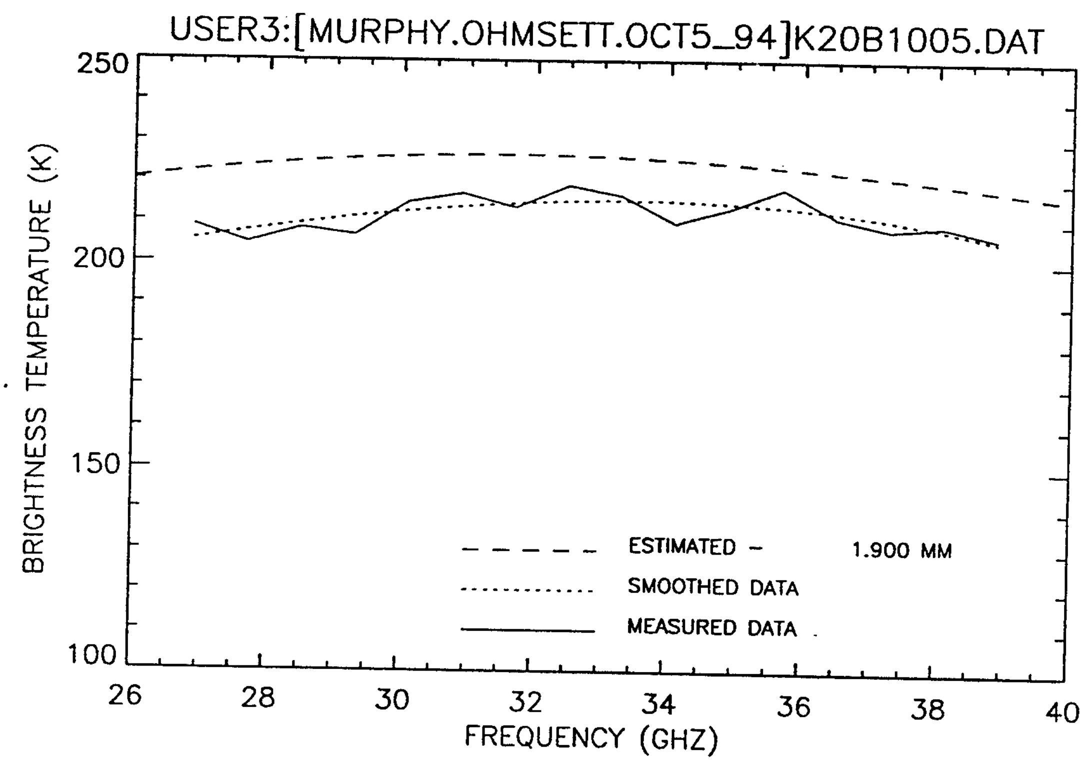

Figure A-10 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, 5 October 1994, Pass 2

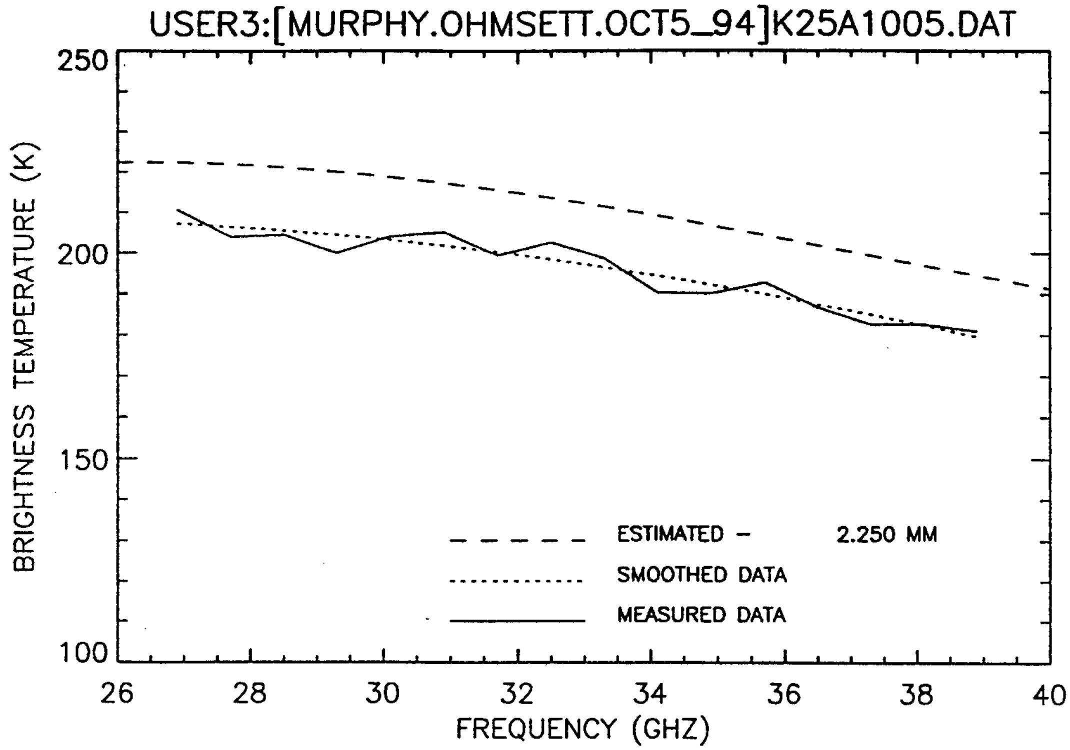

Figure A-11 T^B Versus Frequency Plot for 2.5 mm Uniform Oil Thickness, 5 October 1994, Pass 1

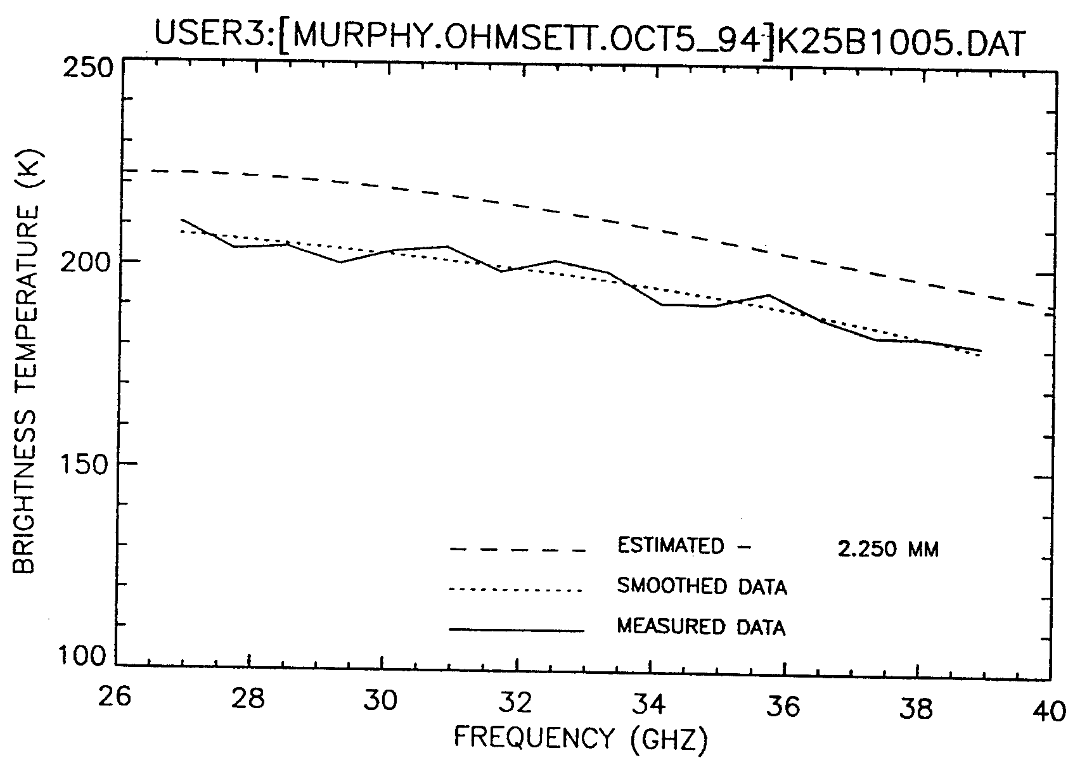

Figure A-12 T^B Versus Frequency Plot for 2.5 mm Uniform Oil Thickness, 5 October 1994, Pass 2

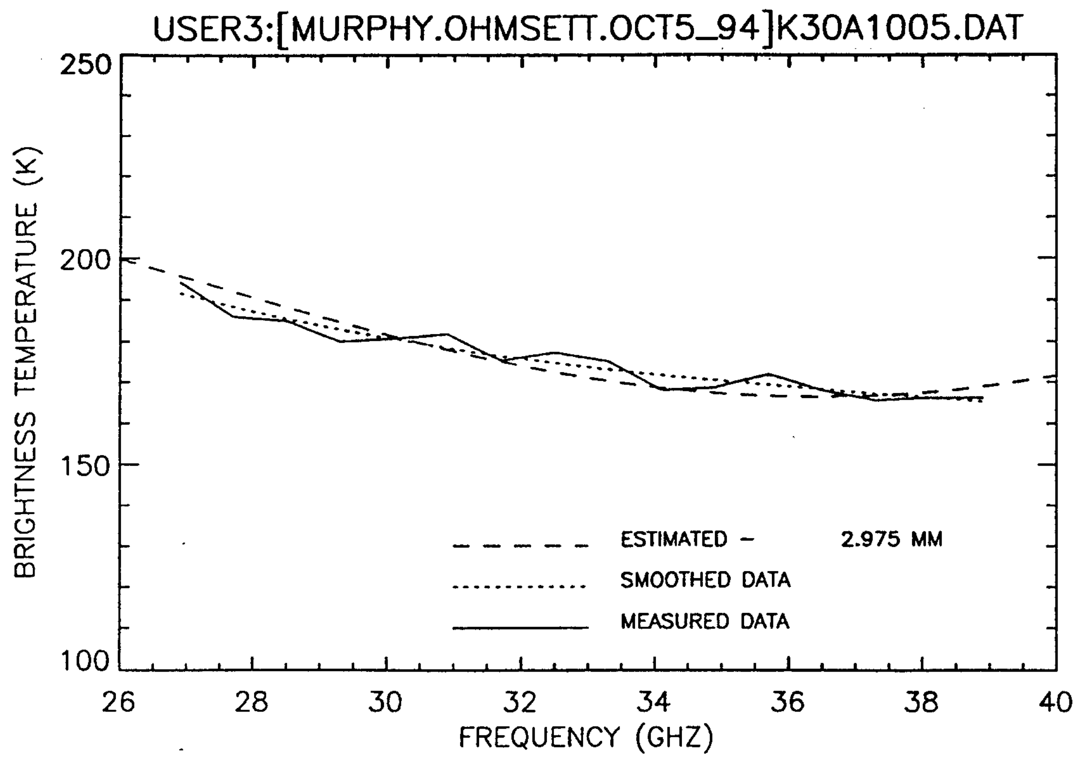

Figure A-13 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, 5 October 1994, Pass 1

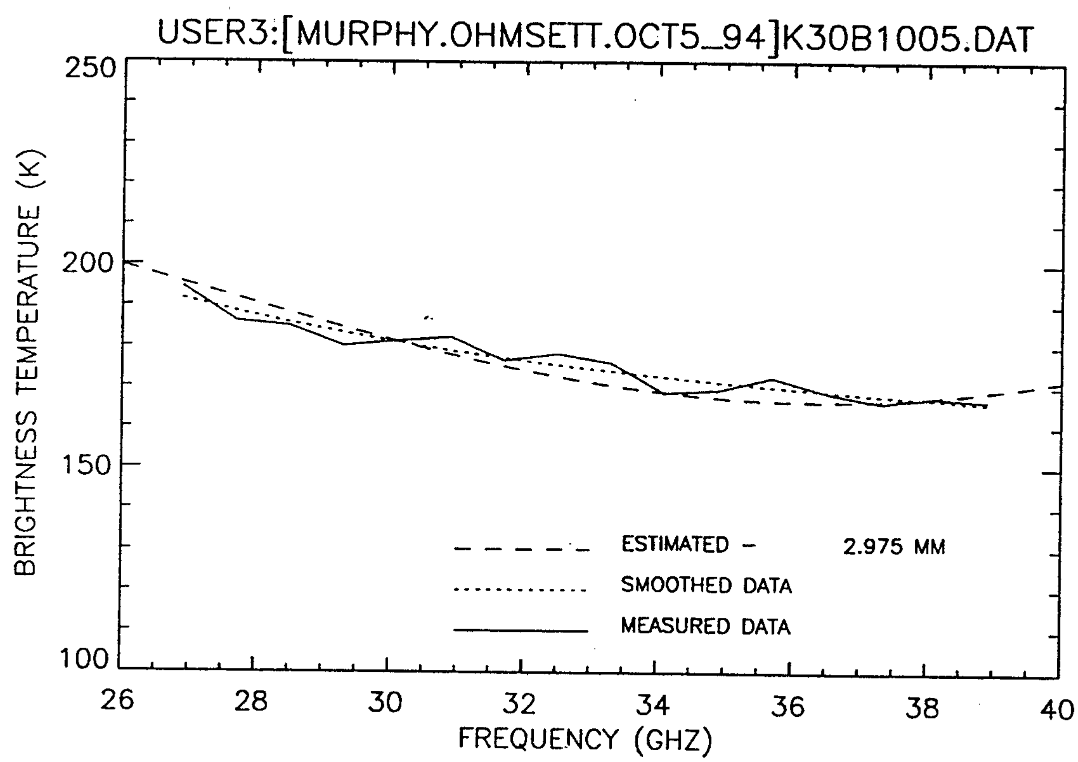

Figure A-14 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, 5 October 1994, Pass 2

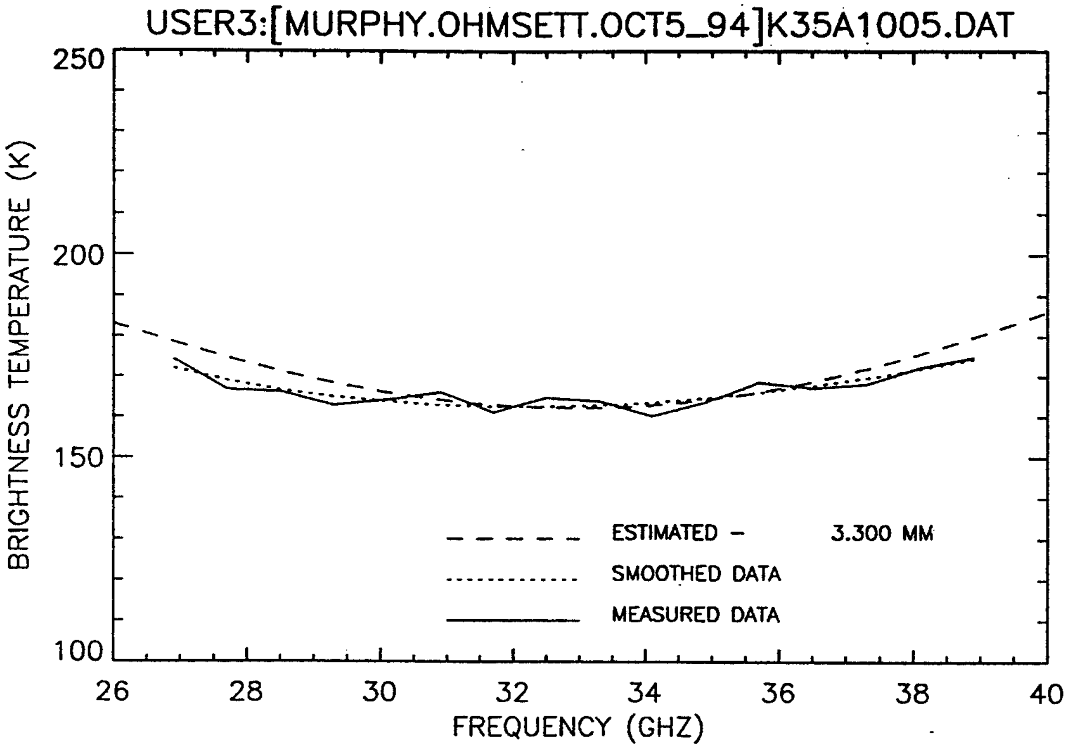

Figure A-15 T^B Versus Frequency Plot for 3.5 mm Uniform Oil Thickness, 5 October 1994, Pass 1

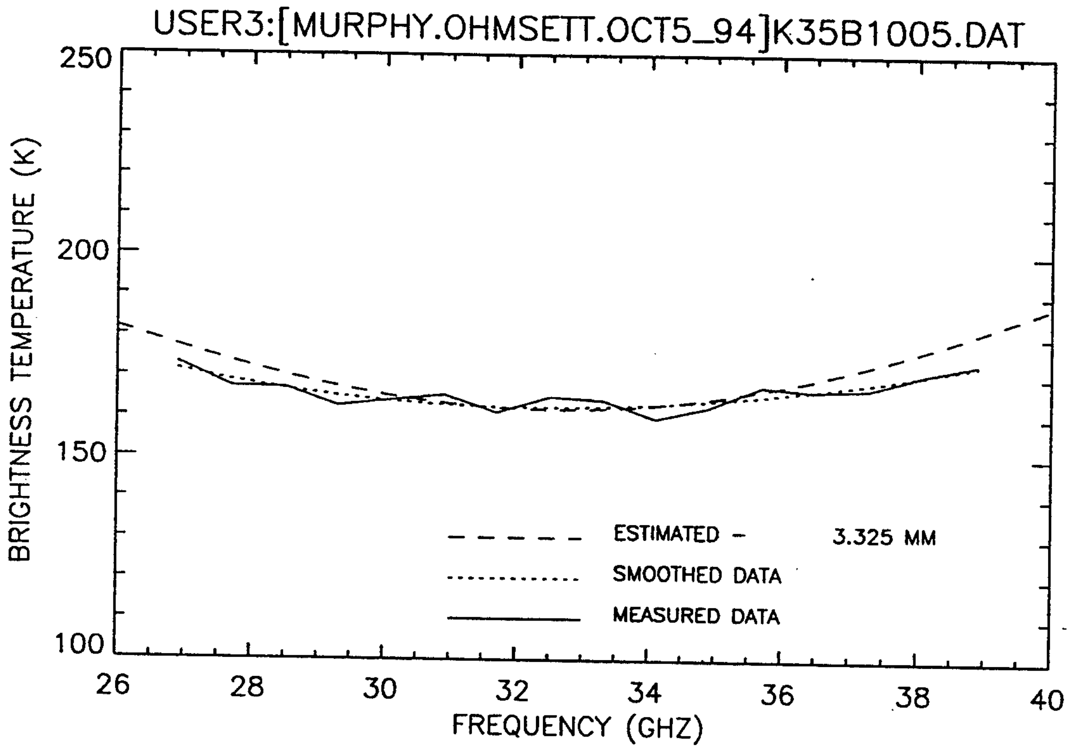

Figure A-16 T^B Versus Frequency Plot for 3.5 mm Uniform Oil Thickness, 5 October 1994, Pass 2

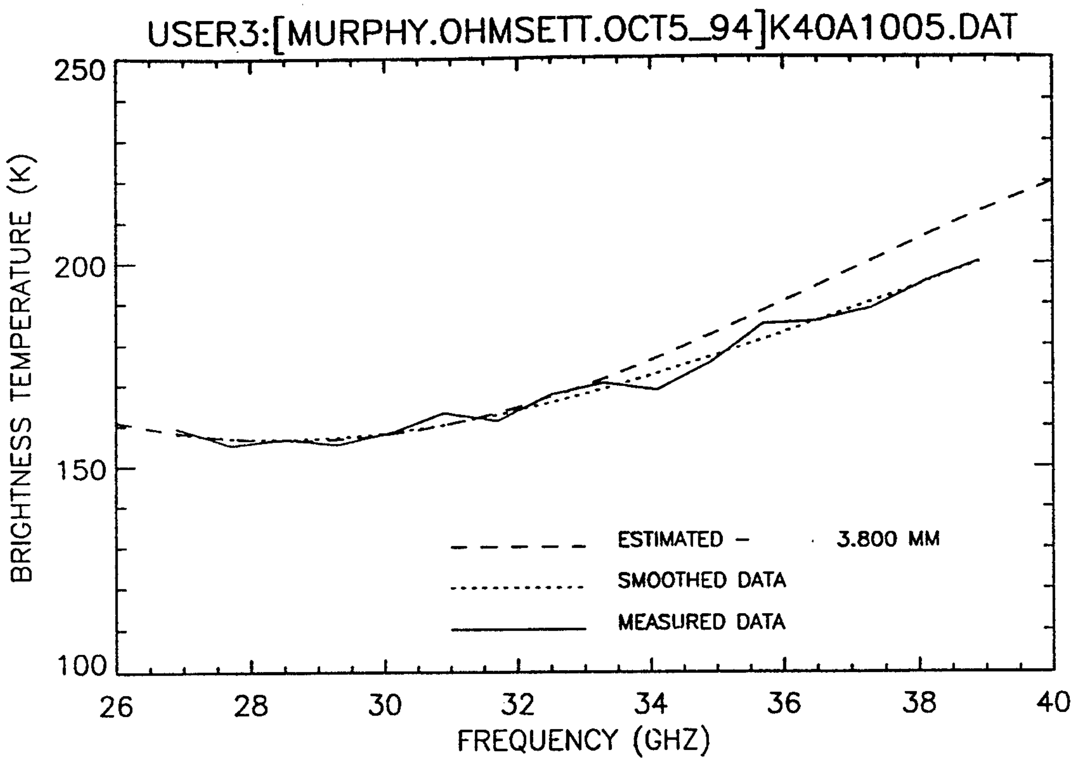

Figure A-17 T^B Versus Frequency Plot for 4.0 mm Uniform Oil Thickness, 5 October 1994, Pass 1

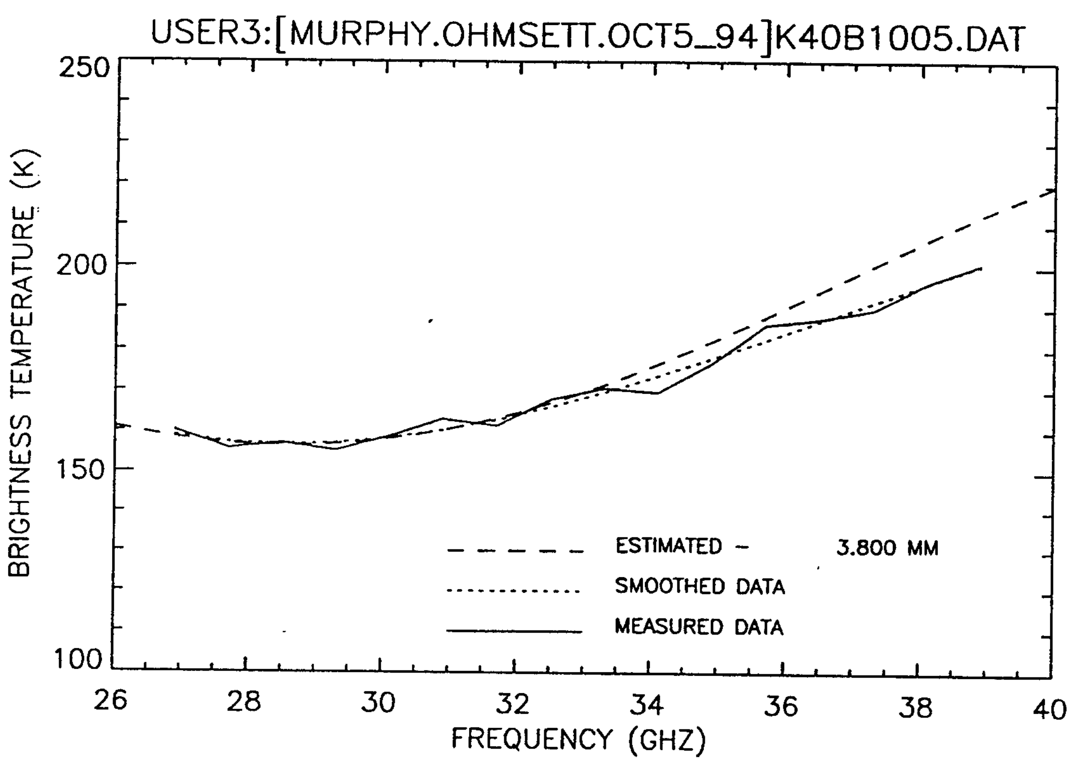

Figure A-18 T^B Versus Frequency Plot for 4.0 mm Uniform Oil Thickness, 5 October 1994, Pass 2

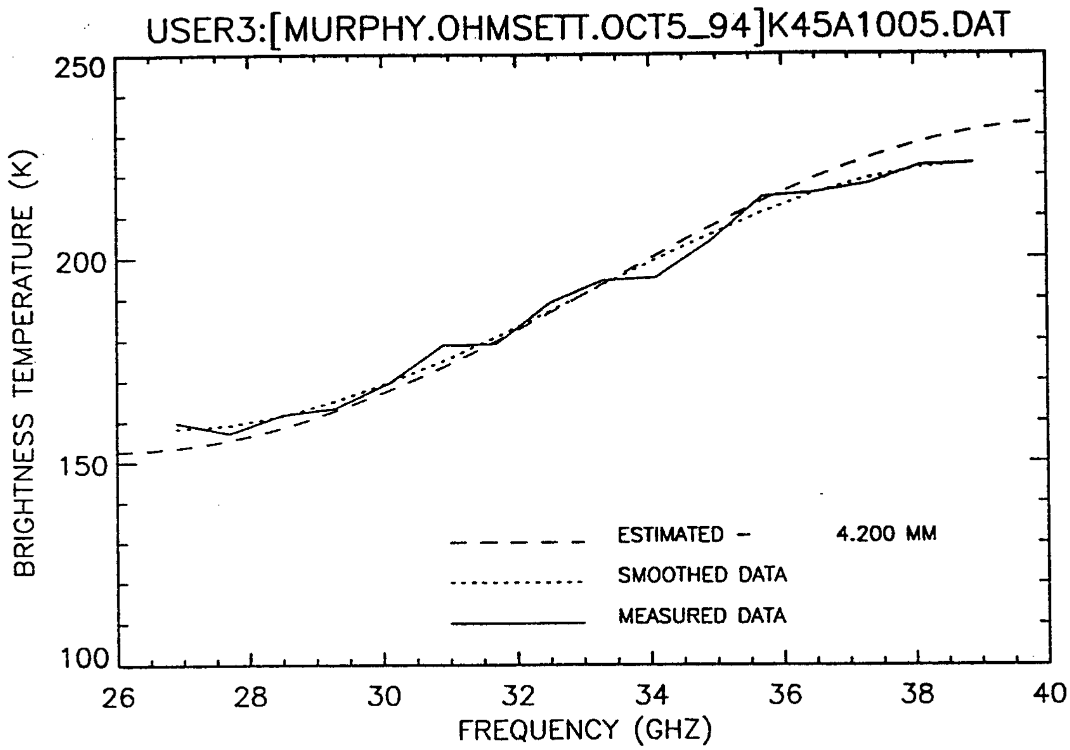

Figure A-19 T^B Versus Frequency Plot for 4.5 mm Uniform Oil Thickness, 5 October 1994, Pass 1

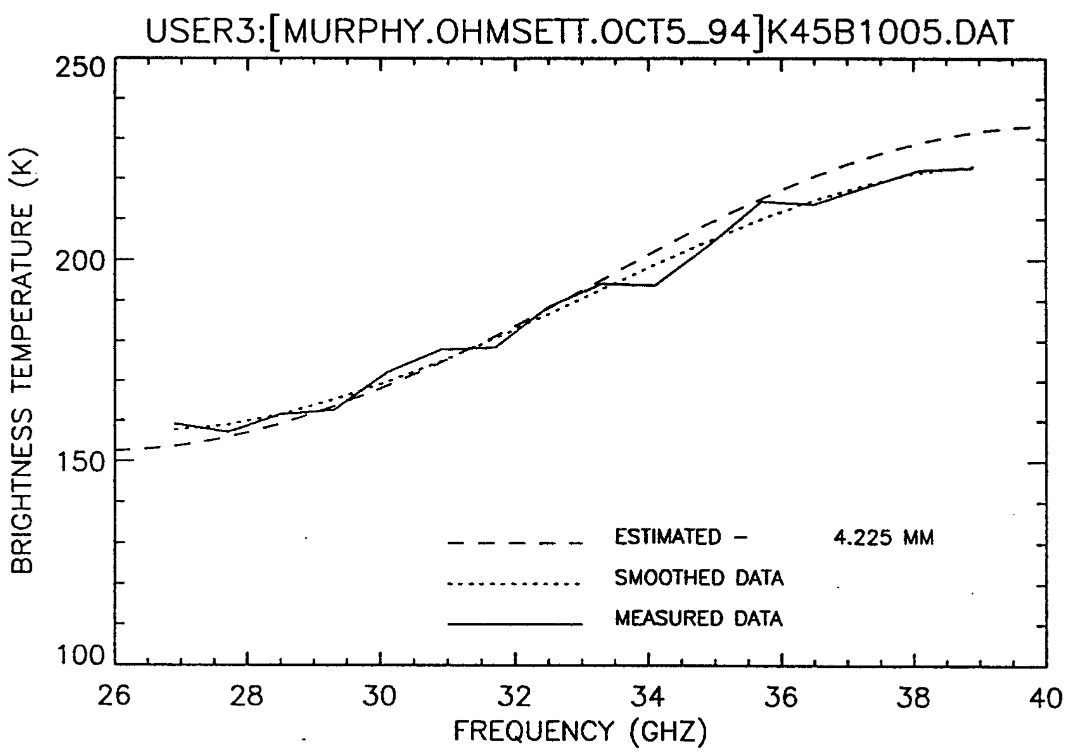

Figure A-20 T^B Versus Frequency Plot for 4.5 mm Uniform Oil Thickness, 5 October 1994, Pass 2

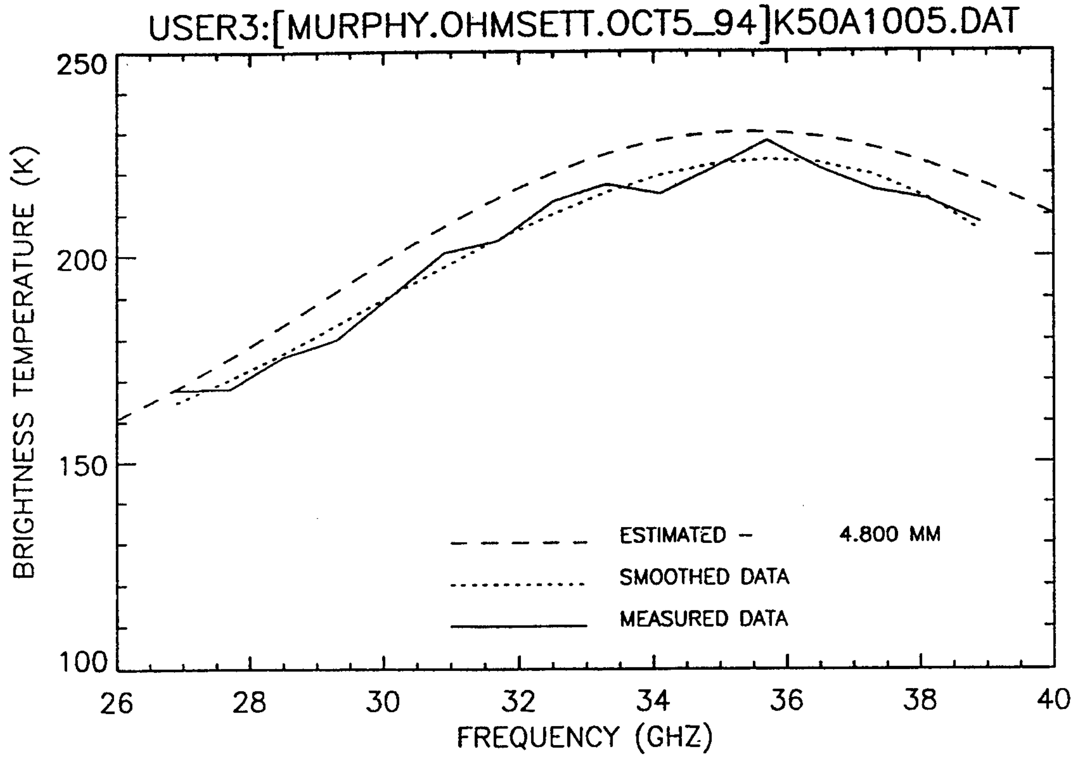

Figure A-21 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, 5 October 1994, Pass 1

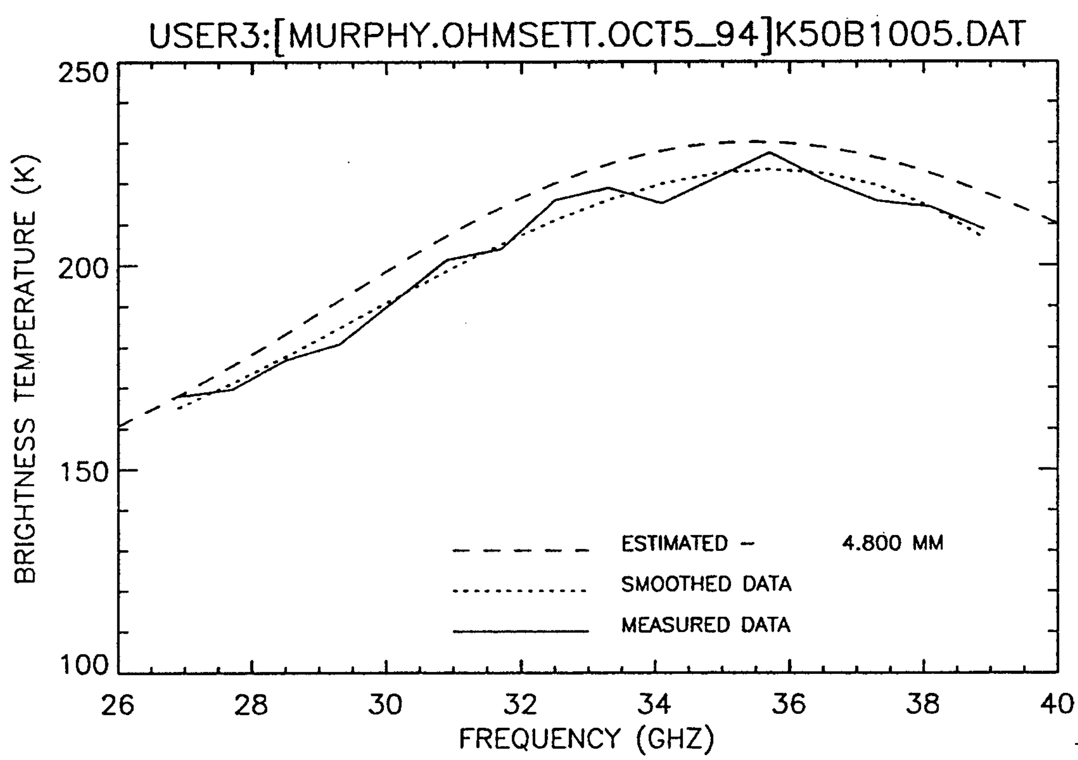

Figure A-22 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, 5 October 1994, Pass 2

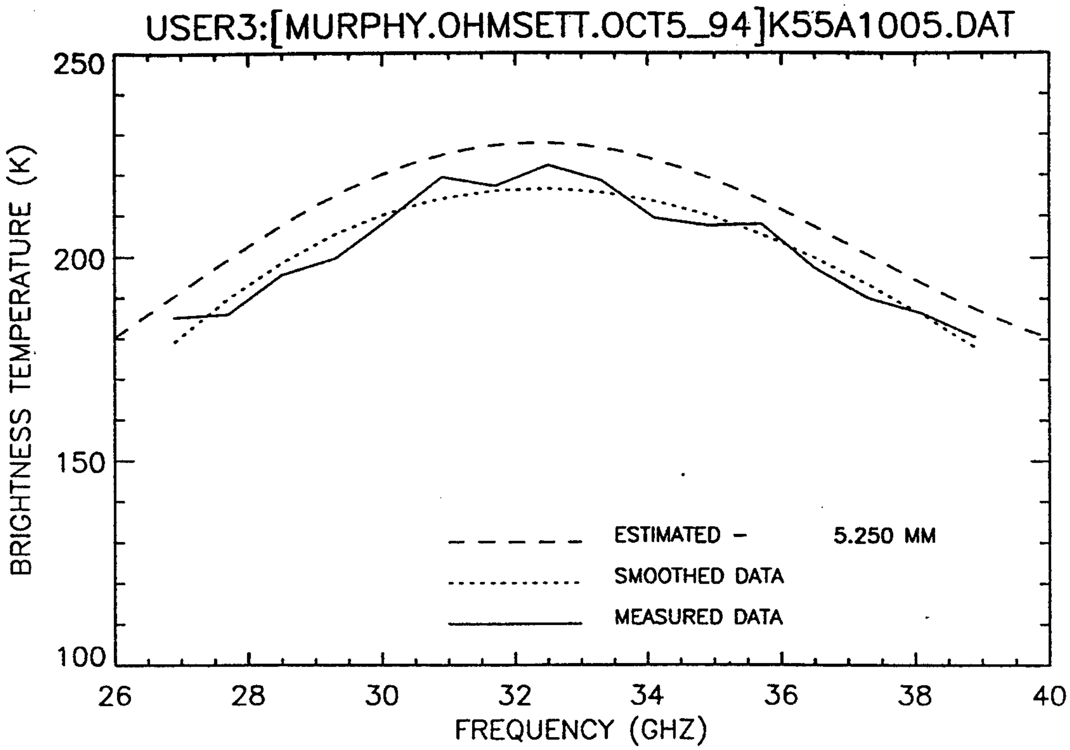

Figure A-23 T^B Versus Frequency Plot for 5.5 mm Uniform Oil Thickness, 5 October 1994, Pass 1

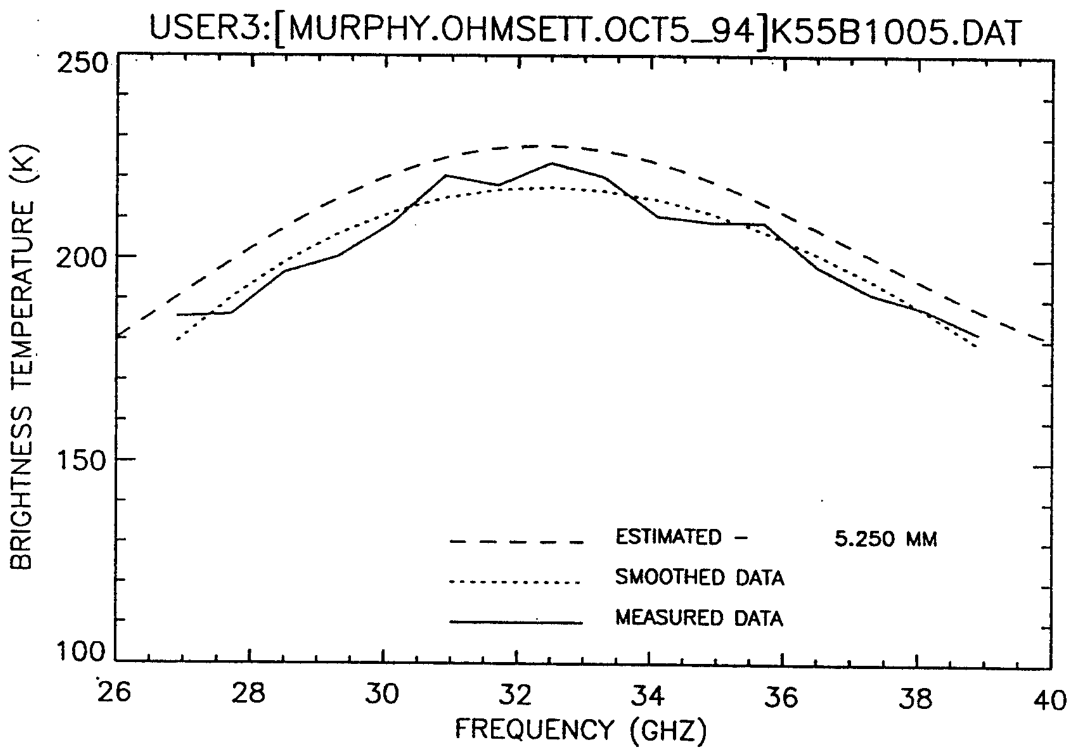

Figure A-24 T^B Versus Frequency Plot for 5.5 mm Uniform Oil Thickness, 5 October 1994, Pass 2

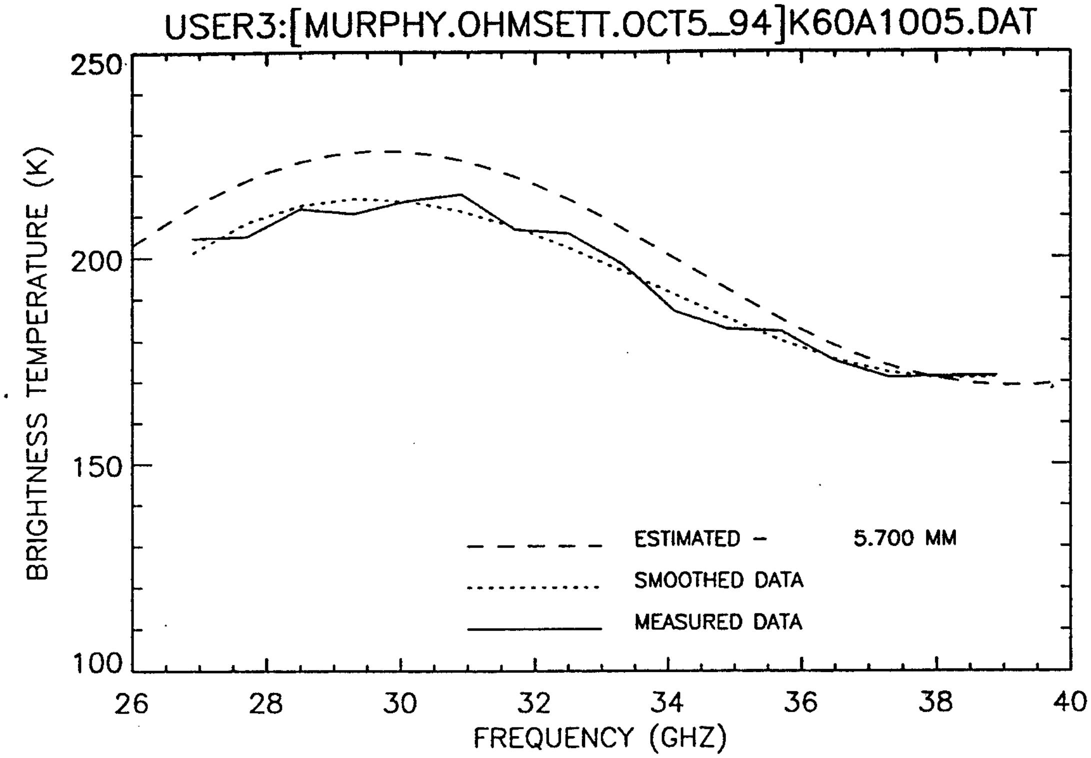

Figure A-25 T^B Versus Frequency Plot for 6.0 mm Uniform Oil Thickness, 5 October 1994, Pass 1

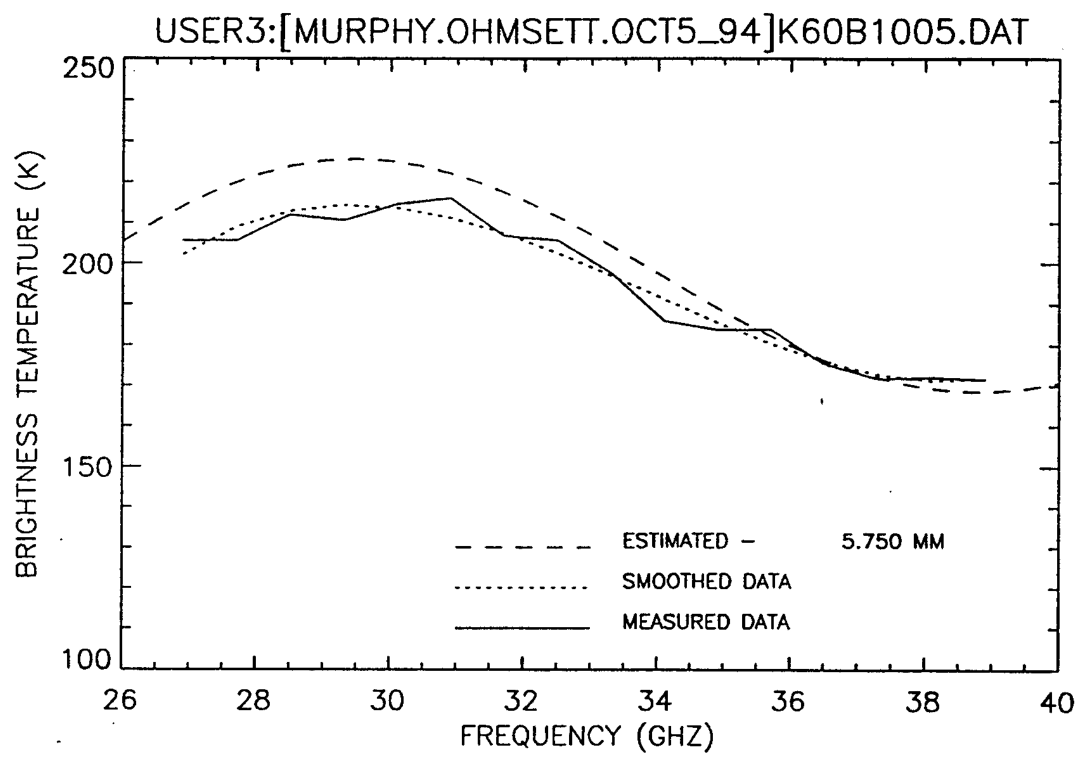

Figure A-26 T^B Versus Frequency Plot for 6.0 mm Uniform Oil Thickness, 5 October 1994, Pass 2

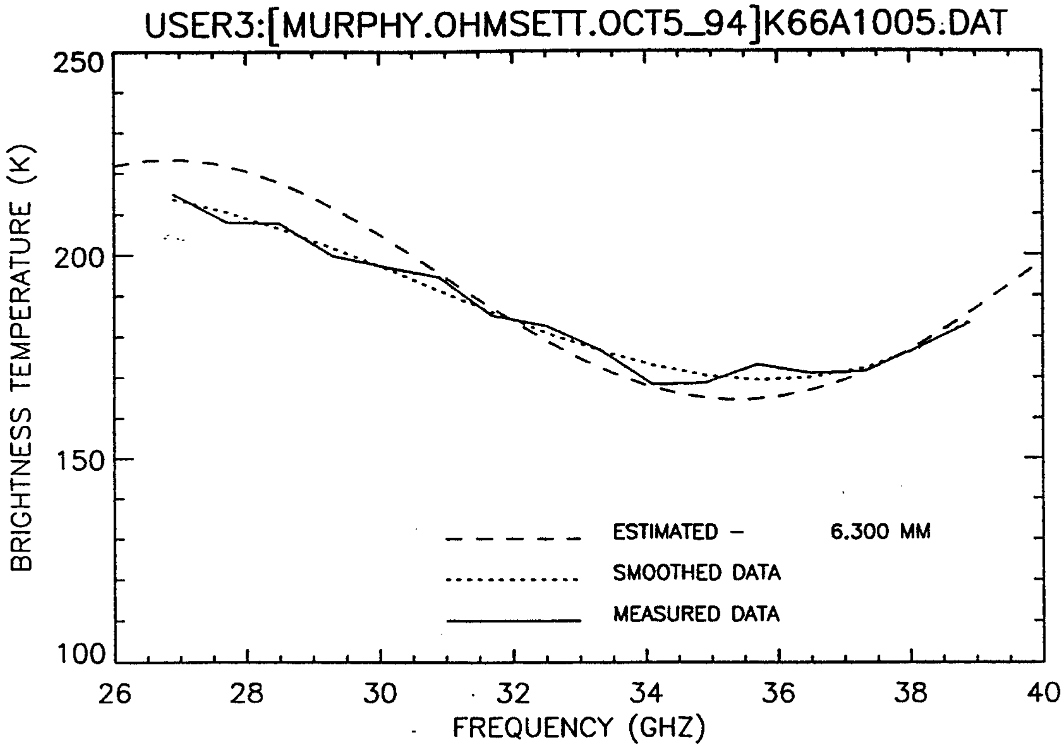

Figure A-27 T^B Versus Frequency Plot for 6.5 mm Uniform Oil Thickness, 5 October 1994, Pass 1

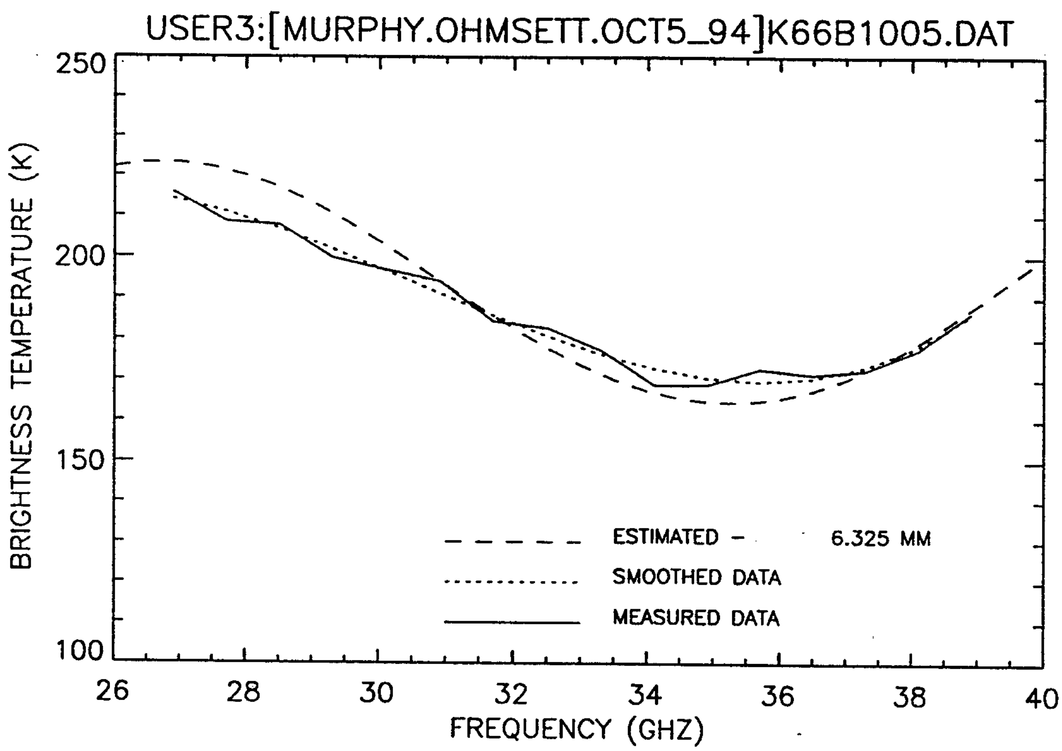

Figure A-28 T^B Versus Frequency Plot for 6.5 mm Uniform Oil Thickness, 5 October 1994, Pass 2

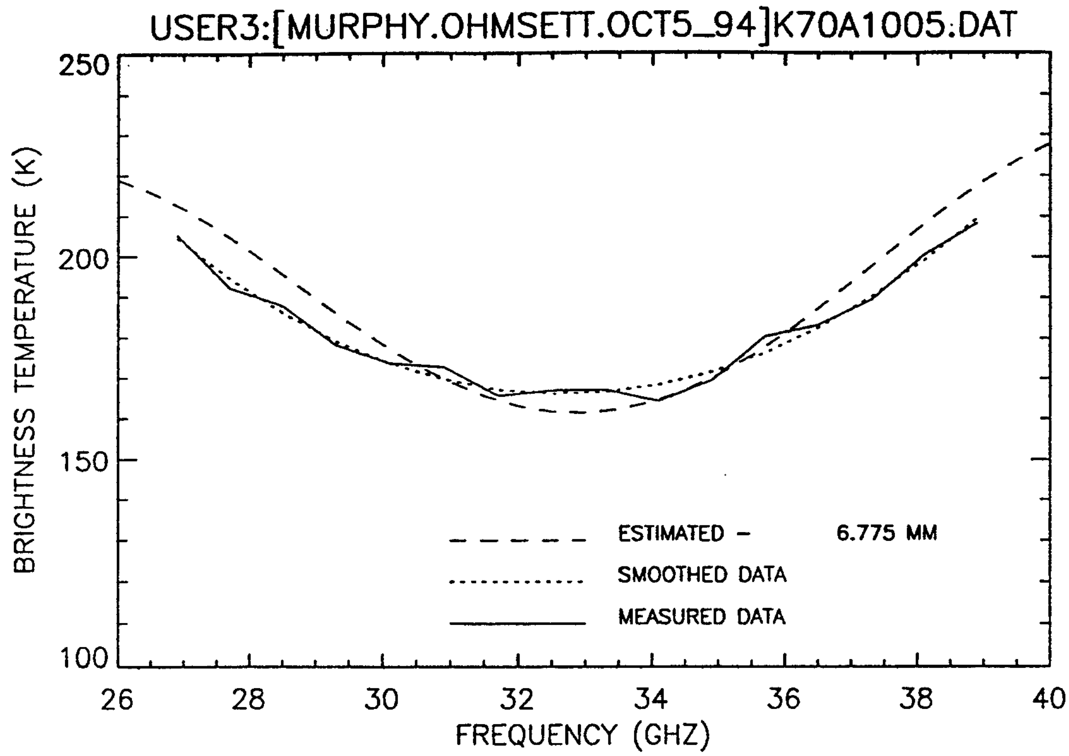

Figure A-29 T^B Versus Frequency Plot for 7.0 mm Uniform Oil Thickness, 5 October 1994, Pass 1

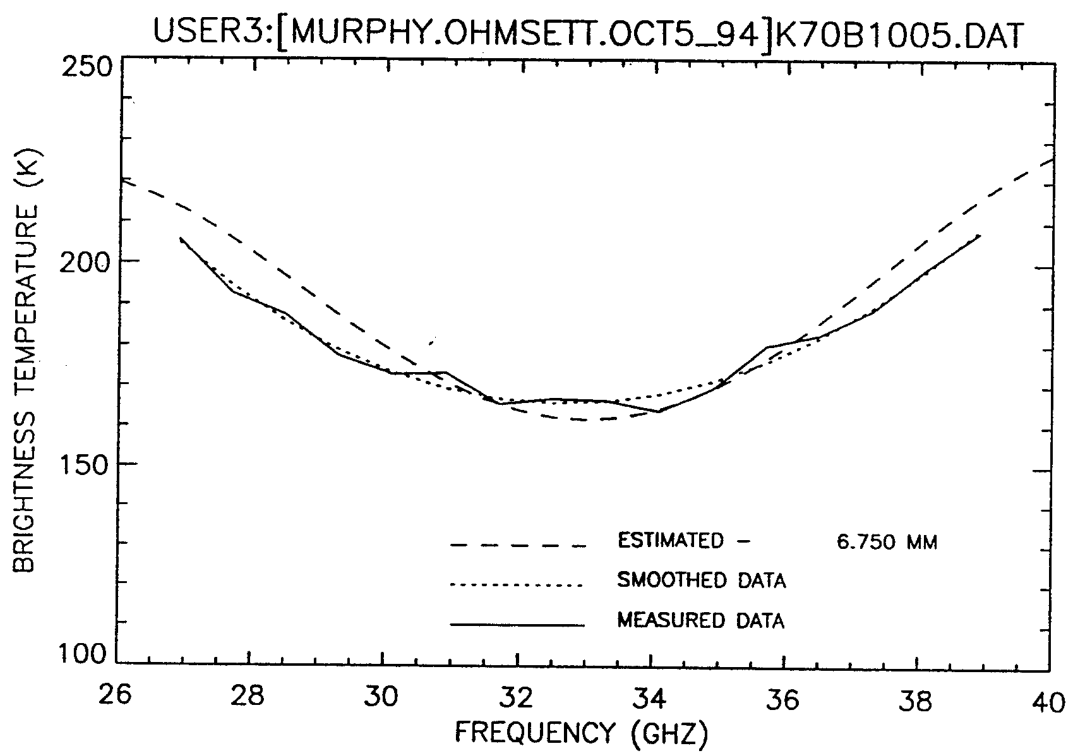

Figure A-30 T^B Versus Frequency Plot for 7.0 mm Uniform Oil Thickness, 5 October 1994, Pass 2

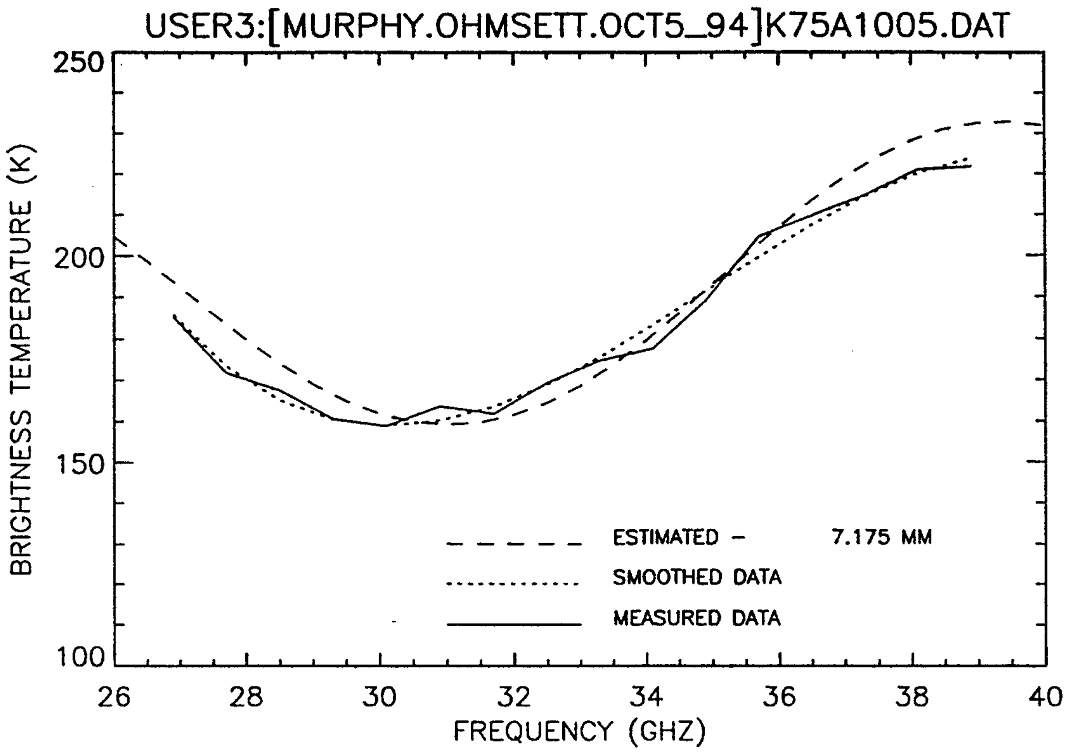

Figure A-31 T^B Versus Frequency Plot for 7.5 mm Uniform Oil Thickness, 5 October 1994, Pass 1

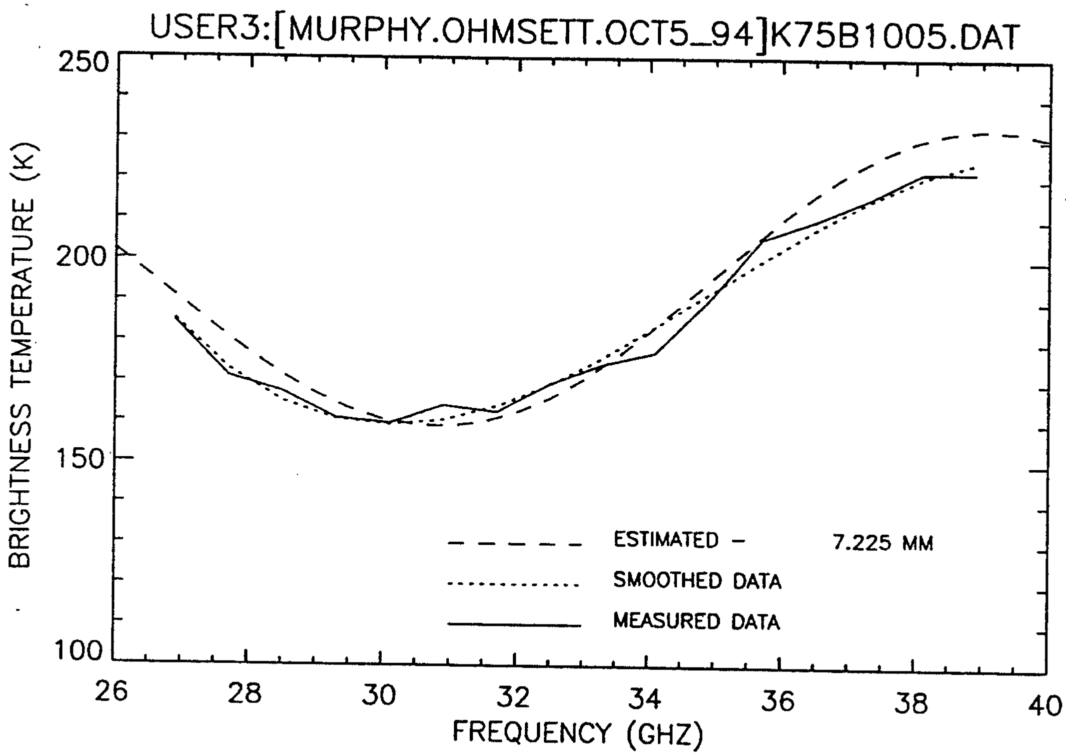

Figure A-32 T^B Versus Frequency Plot for 7.5 mm Uniform Oil Thickness, 5 October 1994, Pass 2

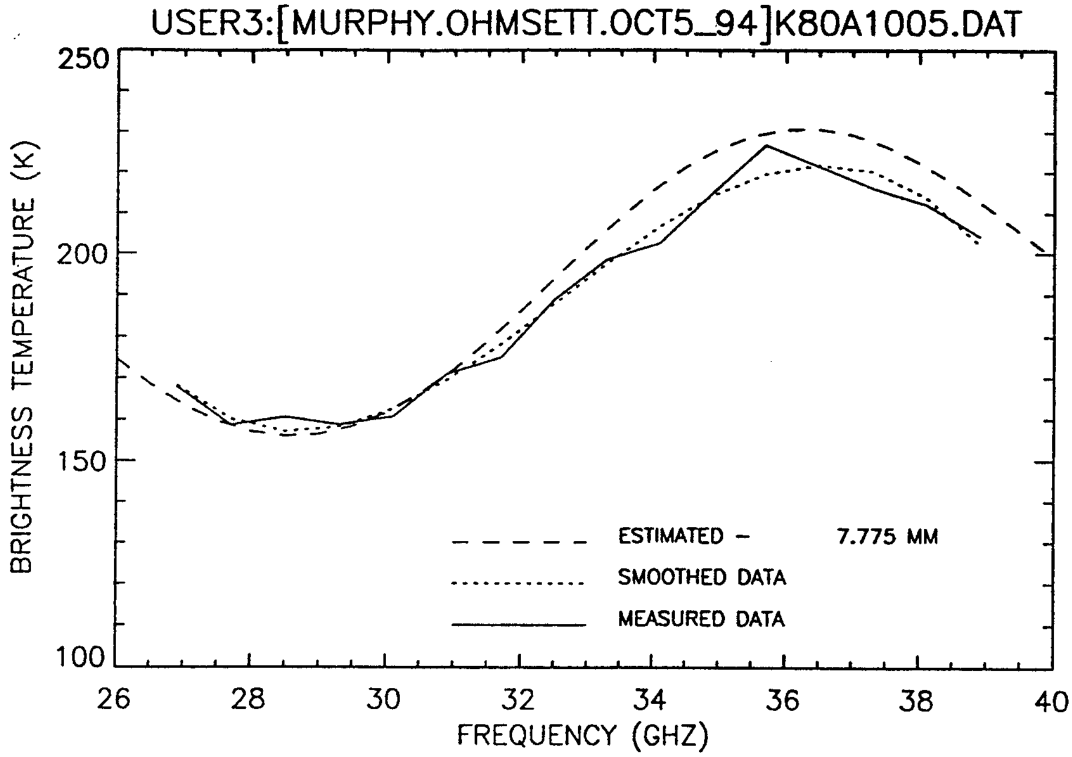

Figure A-33 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, 5 October 1994, Pass 1

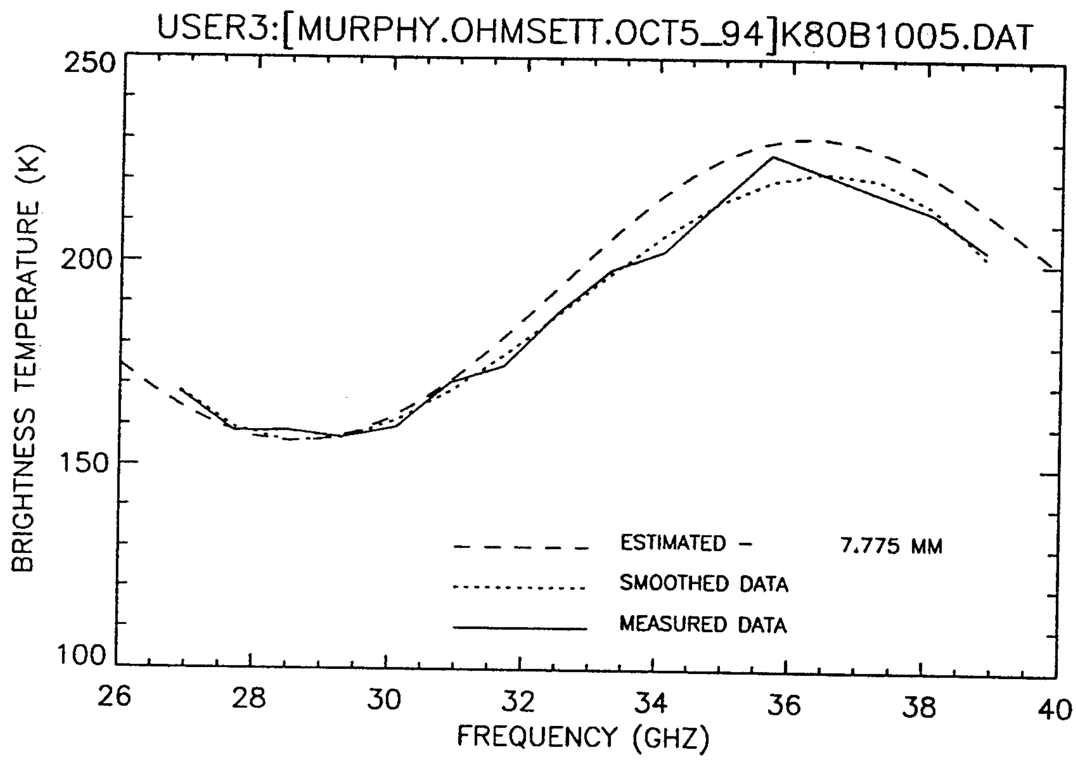

Figure A-34 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, 5 October 1994, Pass 2

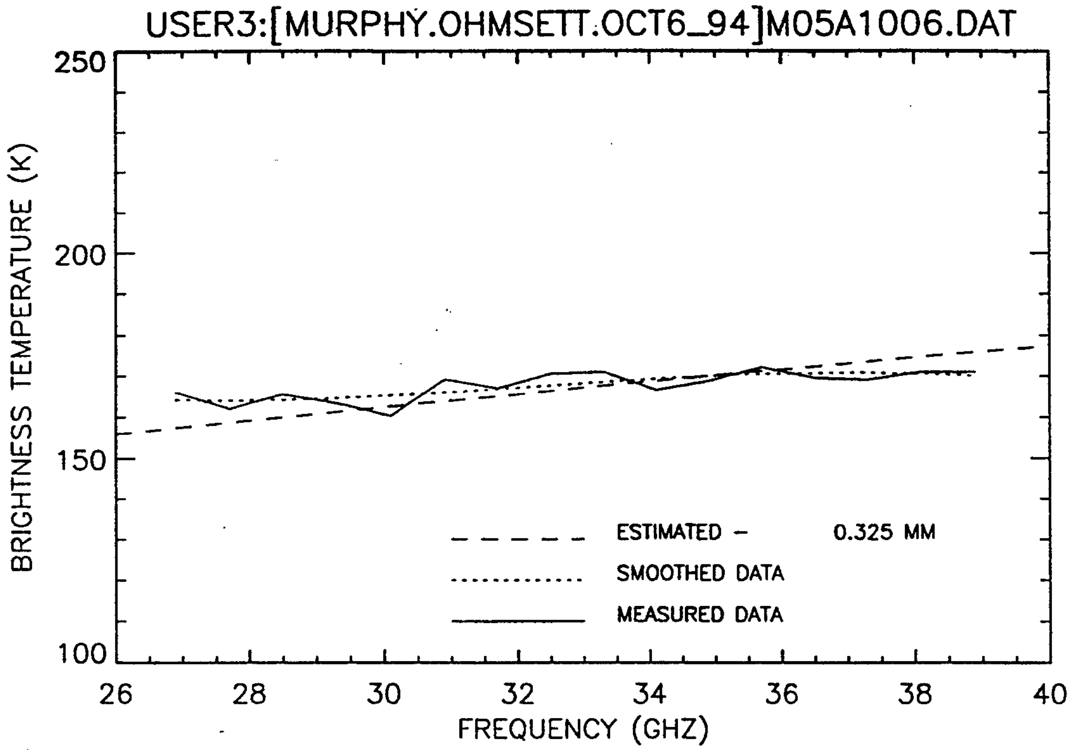

Figure A-35 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, 6 October 1994, Pass 1

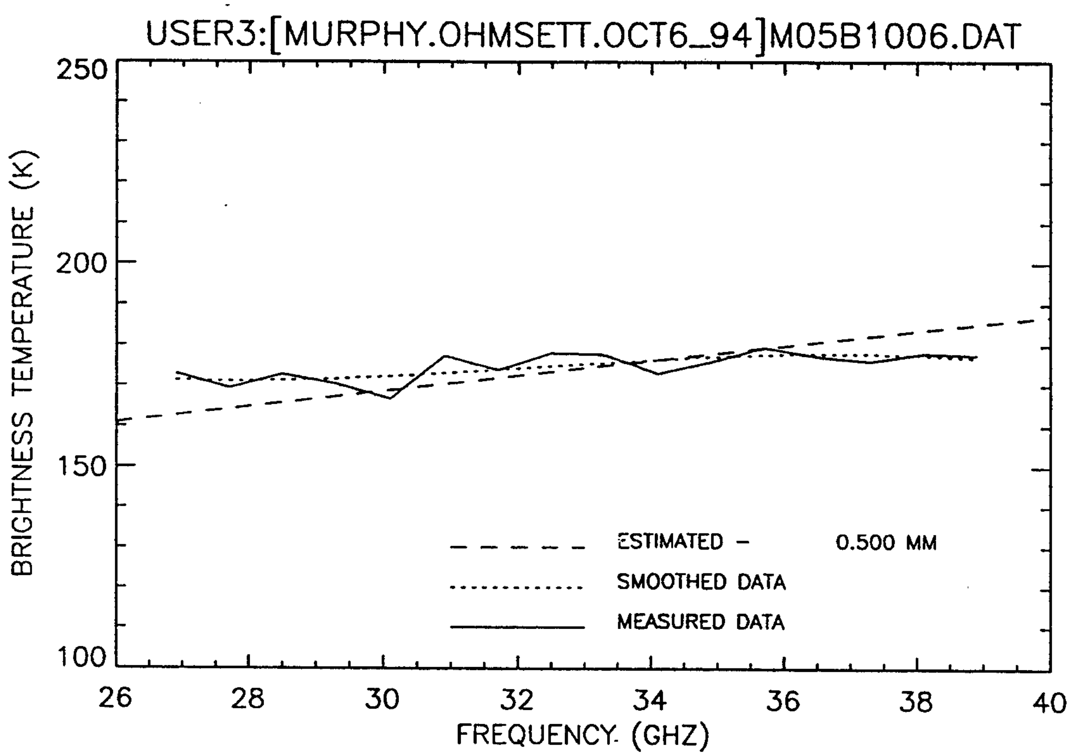

Figure A-36 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, 6 October 1994, Pass 2

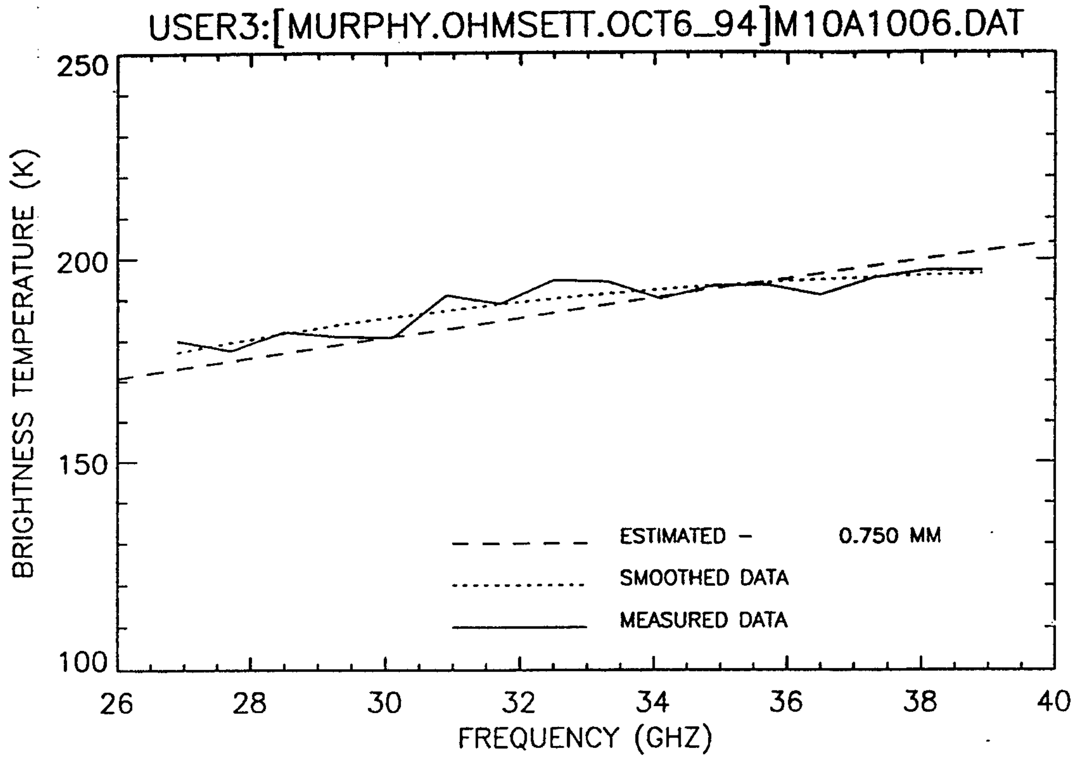

Figure A-37 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, 6 October 1994, Pass 1

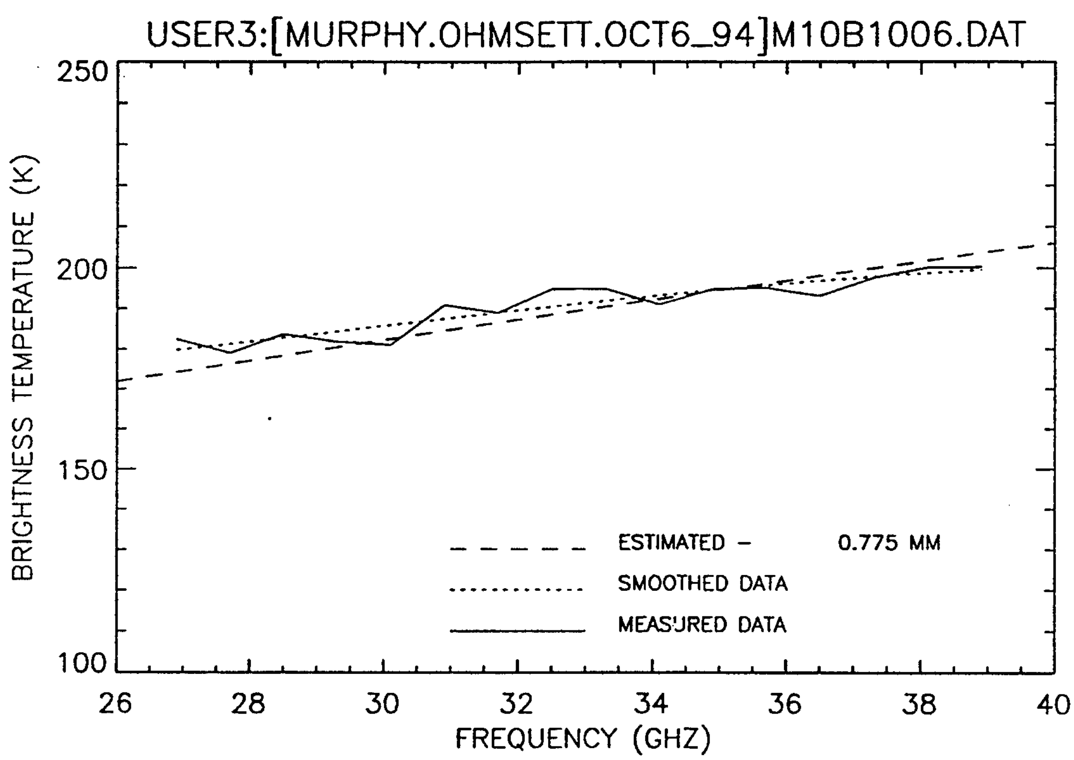

Figure A-38 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, 6 October 1994, Pass 2

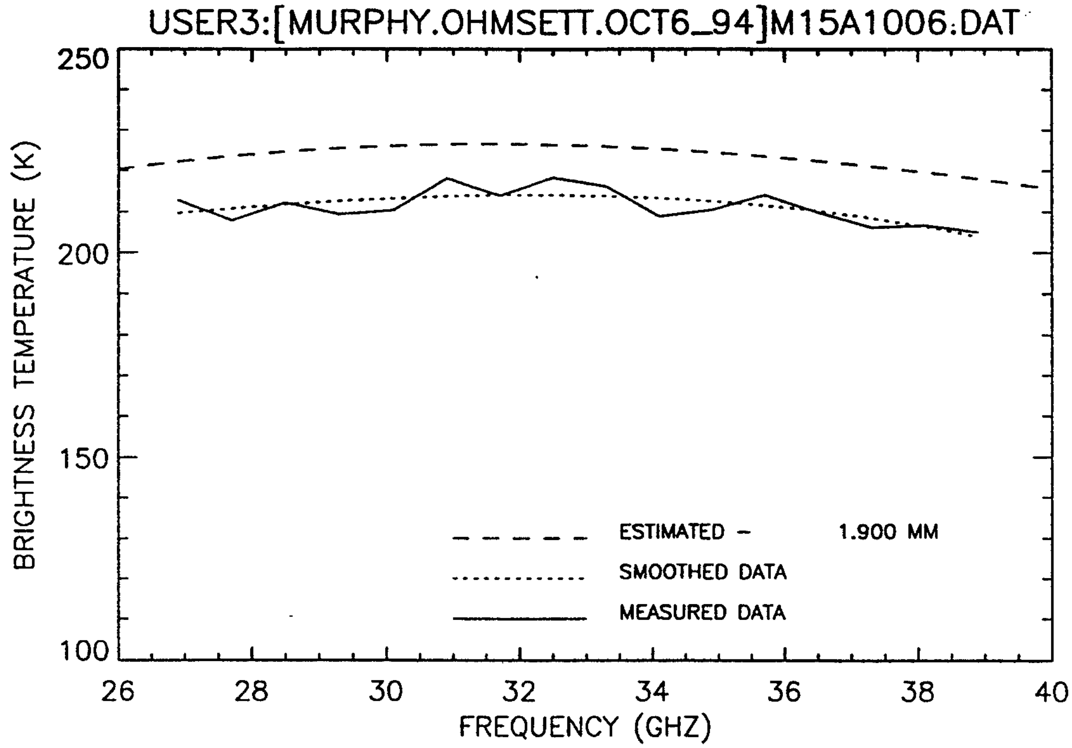

Figure A-39 T^B Versus Frequency Plot for 1.5 mm Uniform Oil Thickness, 6 October 1994, Pass 1

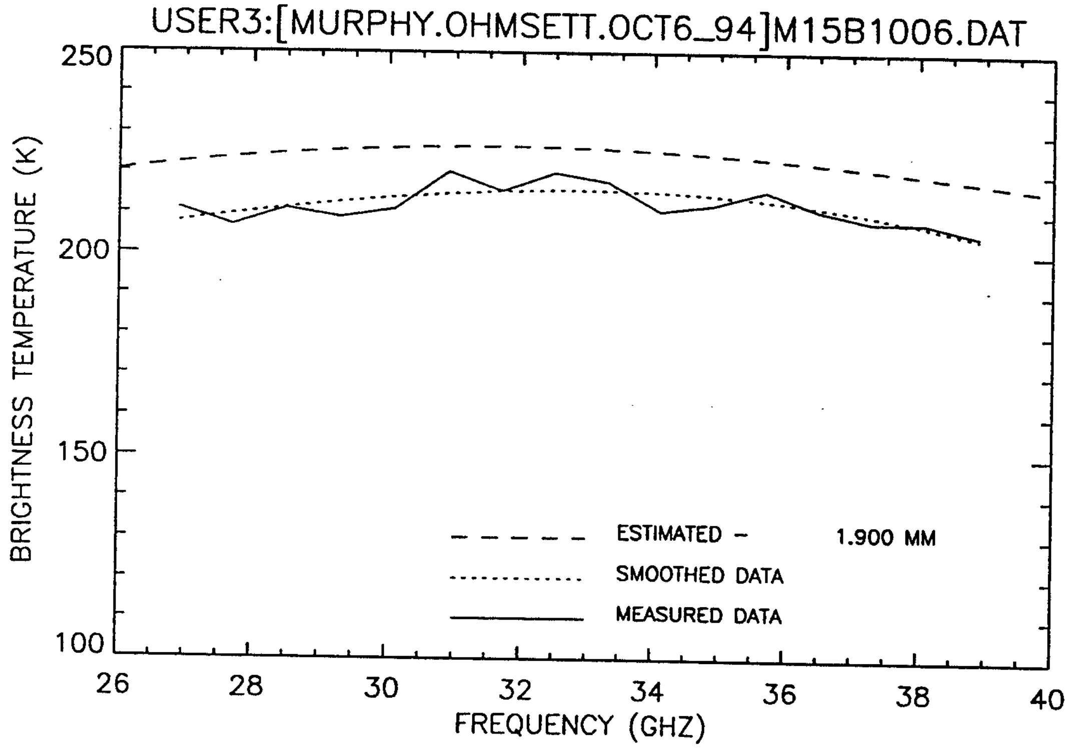

Figure A-40 T^B Versus Frequency Plot for 1.5 mm Uniform Oil Thickness, 6 October 1994, Pass 2

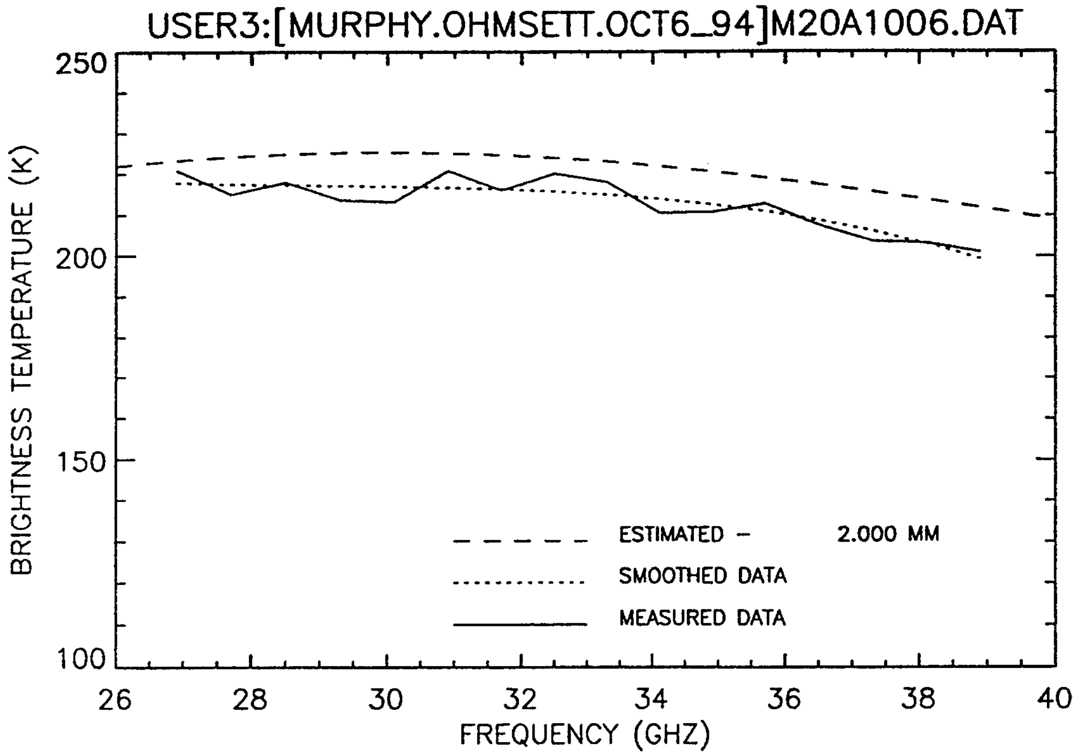

Figure A-41 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, 6 October 1994, Pass 1

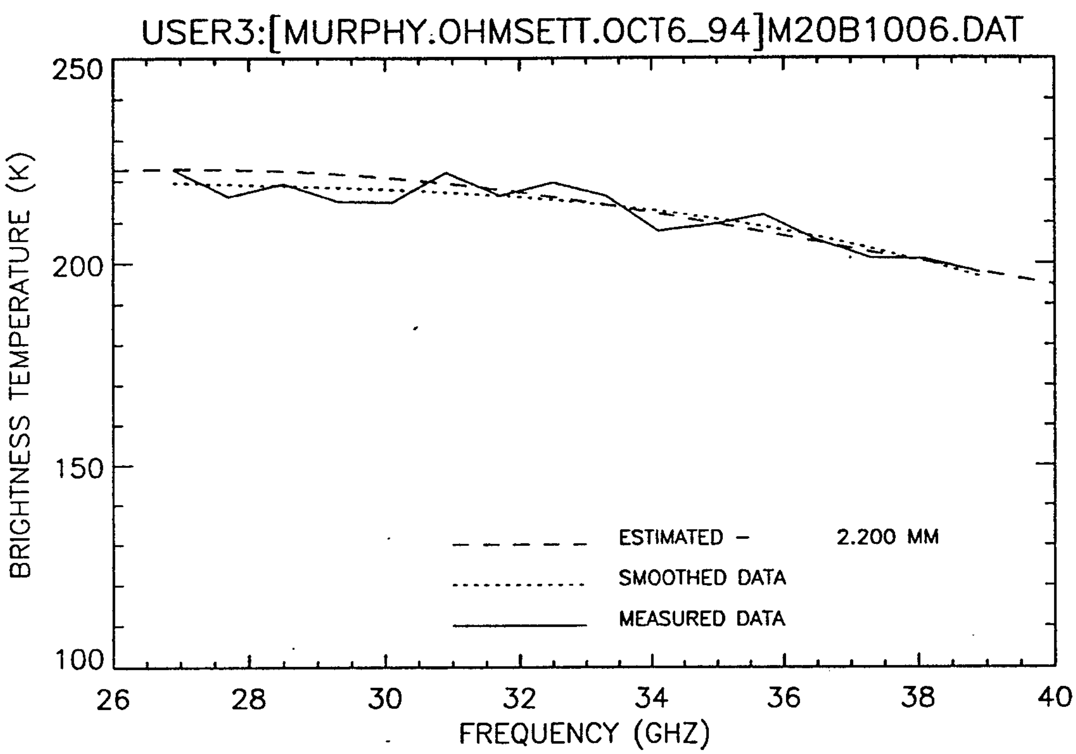

Figure A-42 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, 6 October 1994, Pass 2

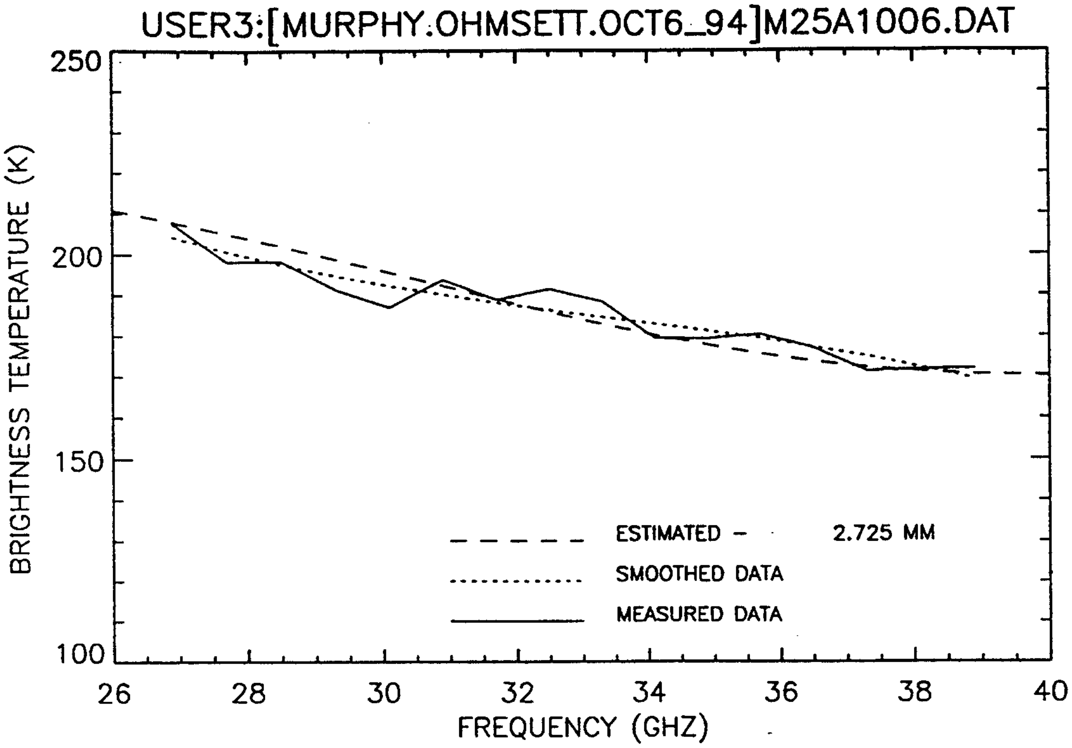

Figure A-43 T^B Versus Frequency Plot for 2.5 mm Uniform Oil Thickness, 6 October 1994, Pass 1

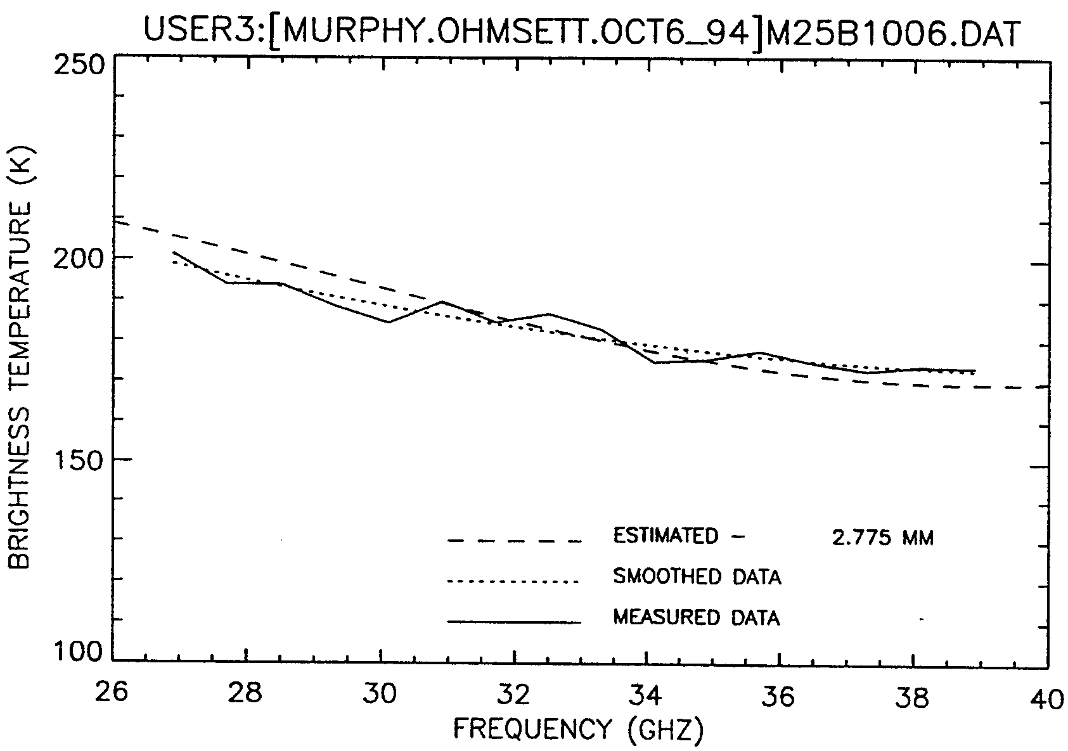

Figure A-44 T^B Versus Frequency Plot for 2.5 mm Uniform Oil Thickness, 6 October 1994, Pass 2

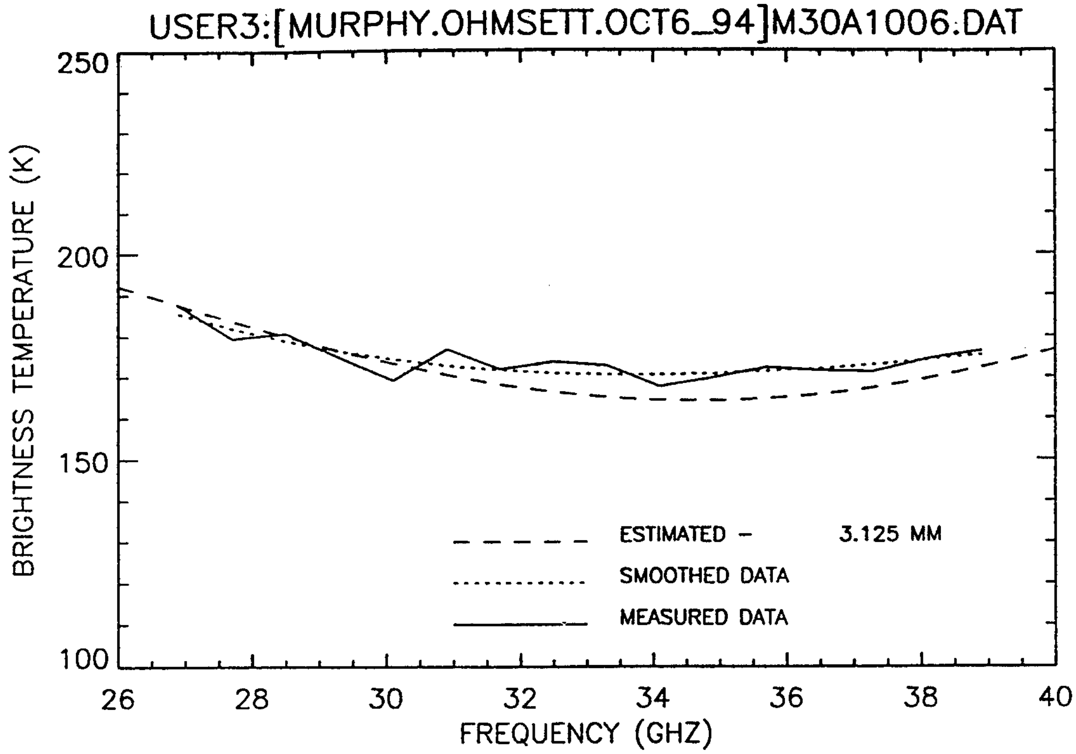

Figure A-45 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, 6 October 1994, Pass 1

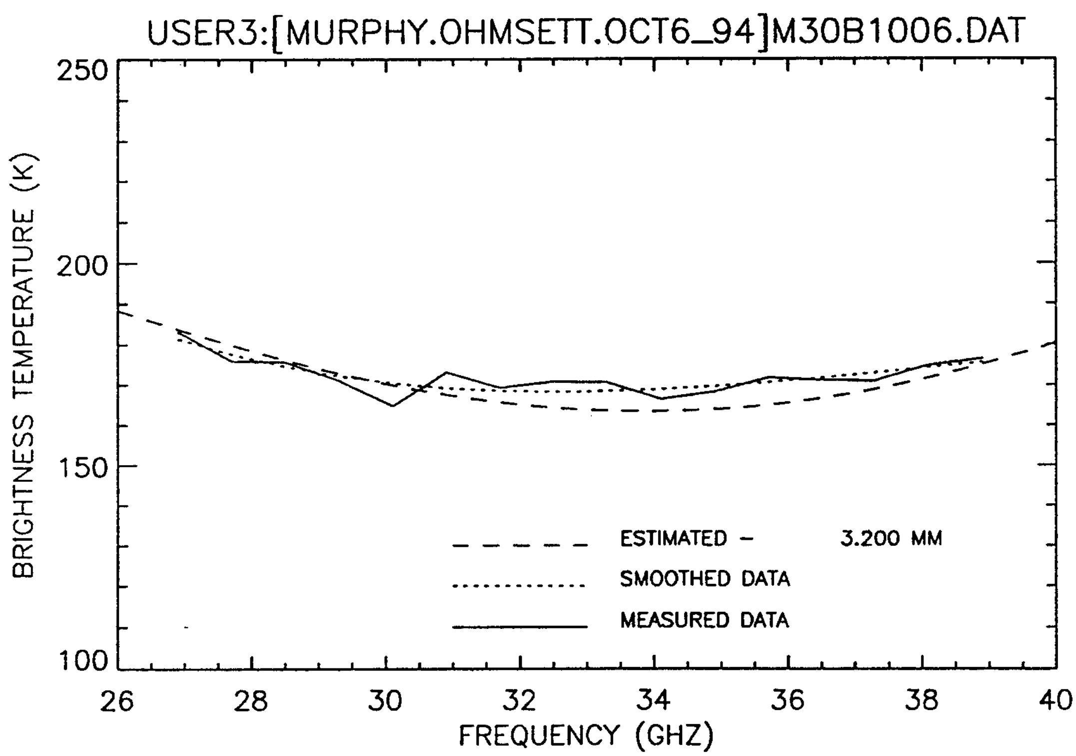

Figure A-46 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, 6 October 1994, Pass 2

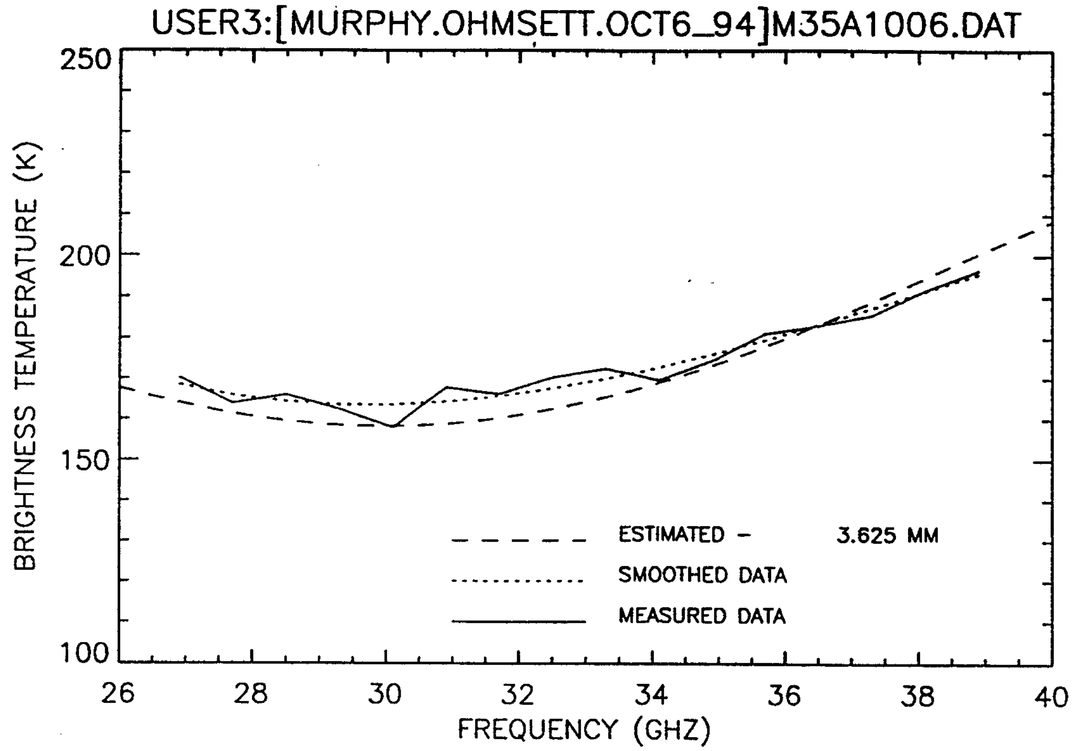

Figure A-47 T^B Versus Frequency Plot for 3.5 mm Uniform Oil Thickness, 6 October 1994. Pass 1

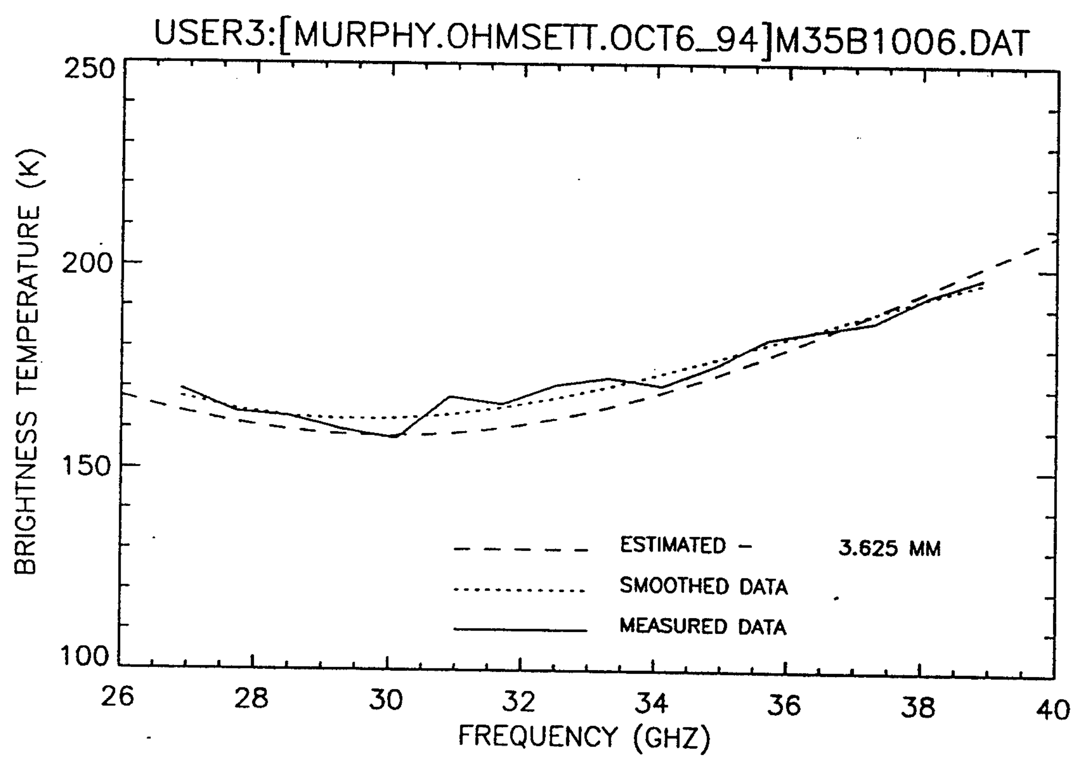

Figure A-48 T^B Versus Frequency Plot for 3.5 mm Uniform Oil Thickness, 6 October 1994, Pass 2

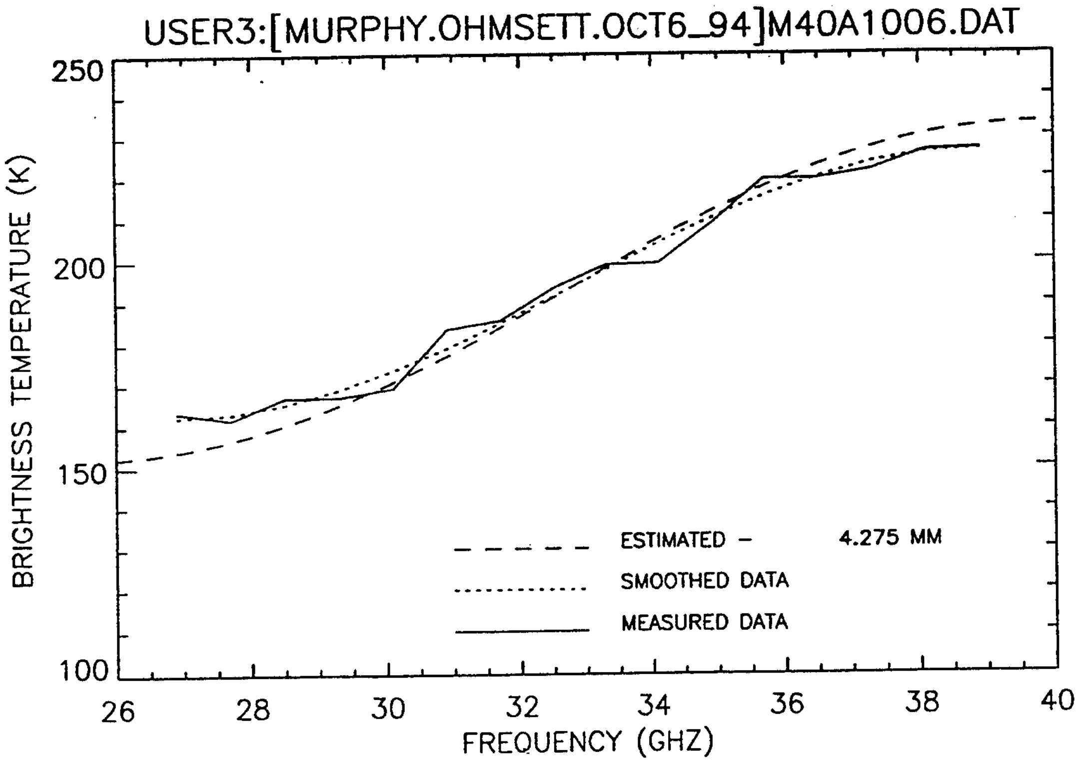

Figure A-49 T^B Versus Frequency Plot for 4.0 mm Uniform Oil Thickness, 6 October 1994. Pass 1

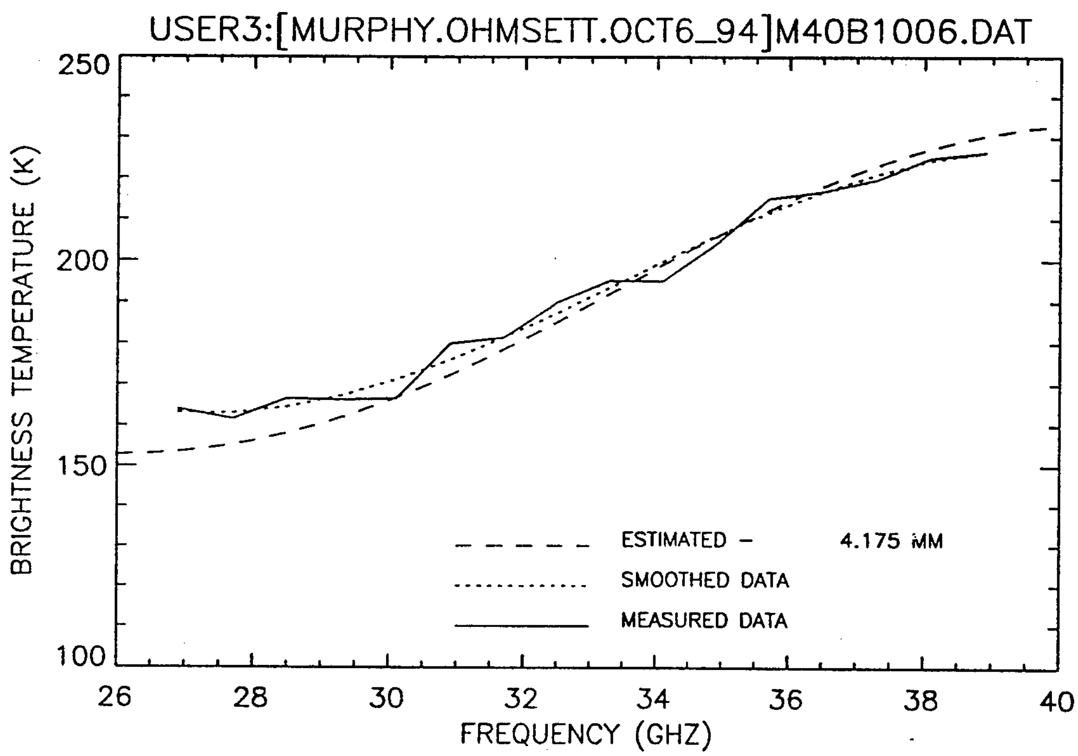

Figure A-50 T^B Versus Frequency Plot for 4.0 mm Uniform Oil Thickness, 6 October 1994, Pass 2

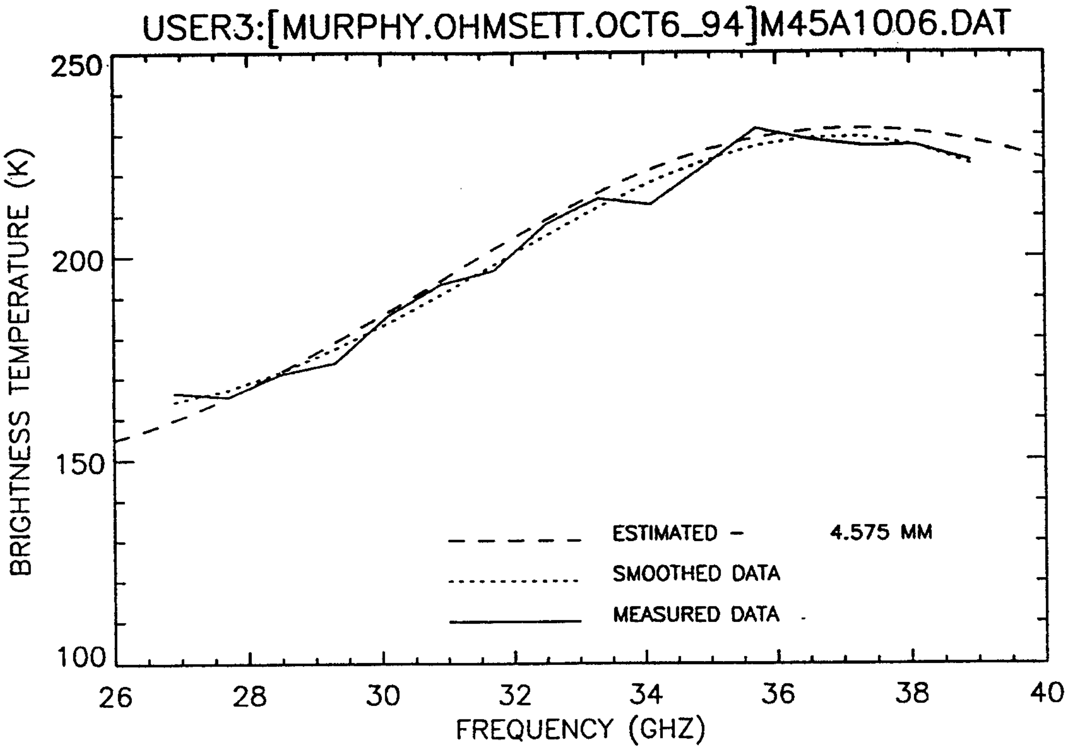

Figure A-51 T^B Versus Frequency Plot for 4.5 mm Uniform Oil Thickness, 6 October 1994, Pass 1

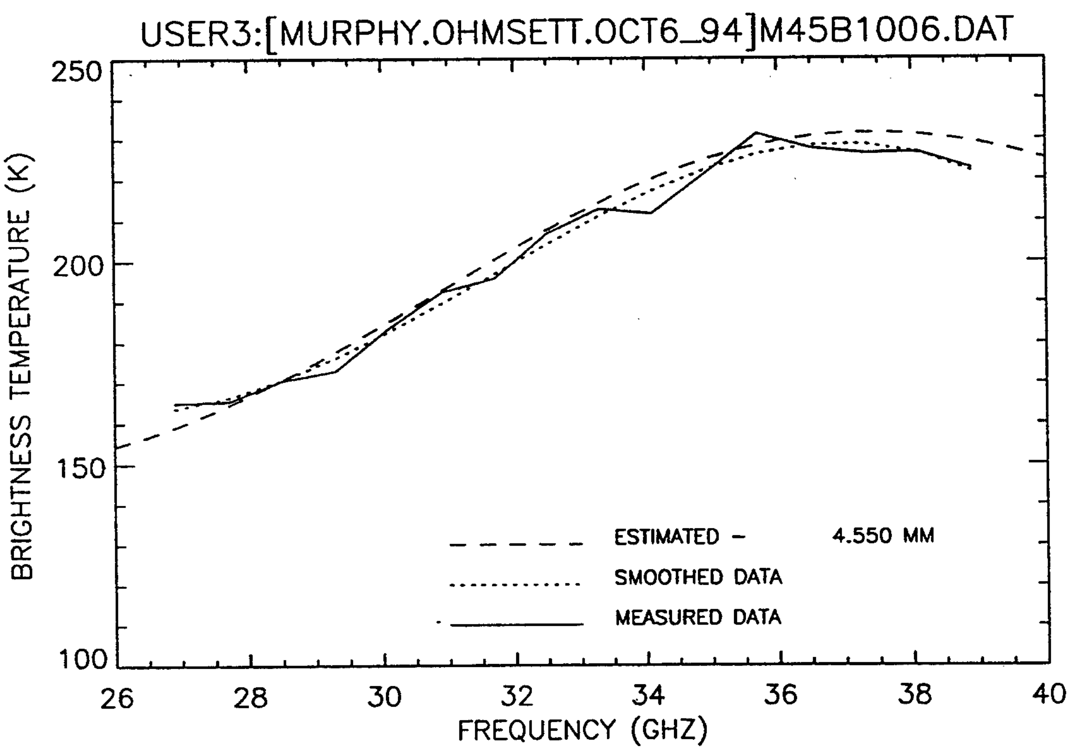

Figure A-52 T^B Versus Frequency Plot for 4.5 mm Uniform Oil Thickness, 6 October 1994, Pass 2

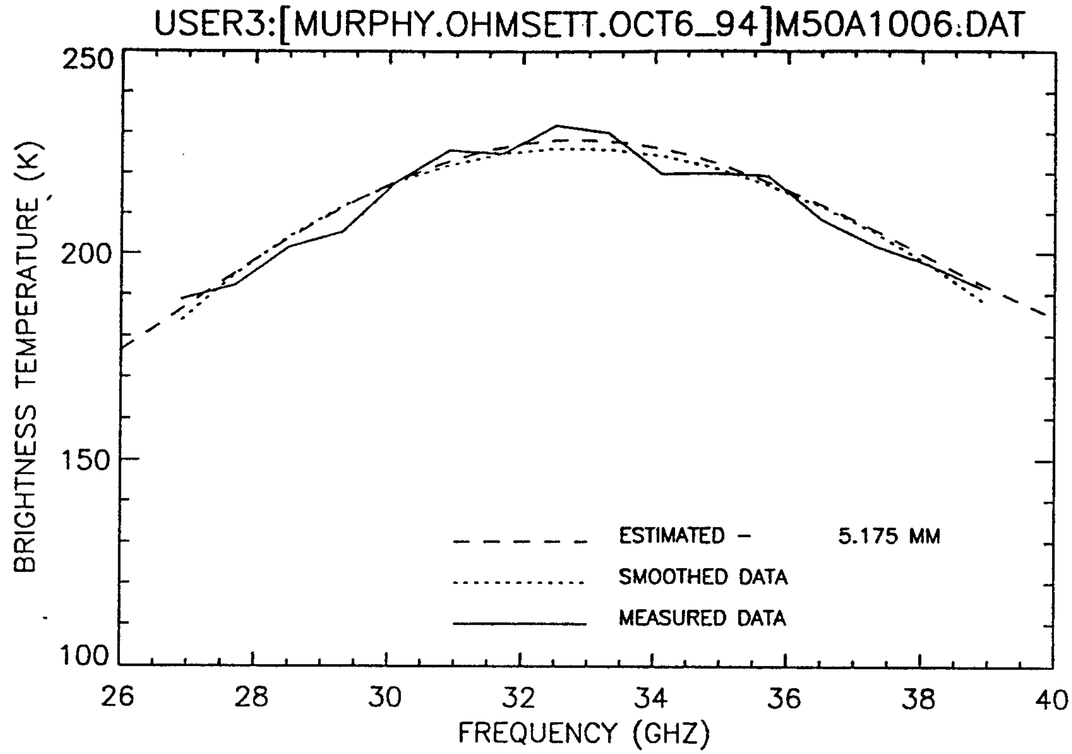

Figure A-53 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, 6 October 1994, Pass 1

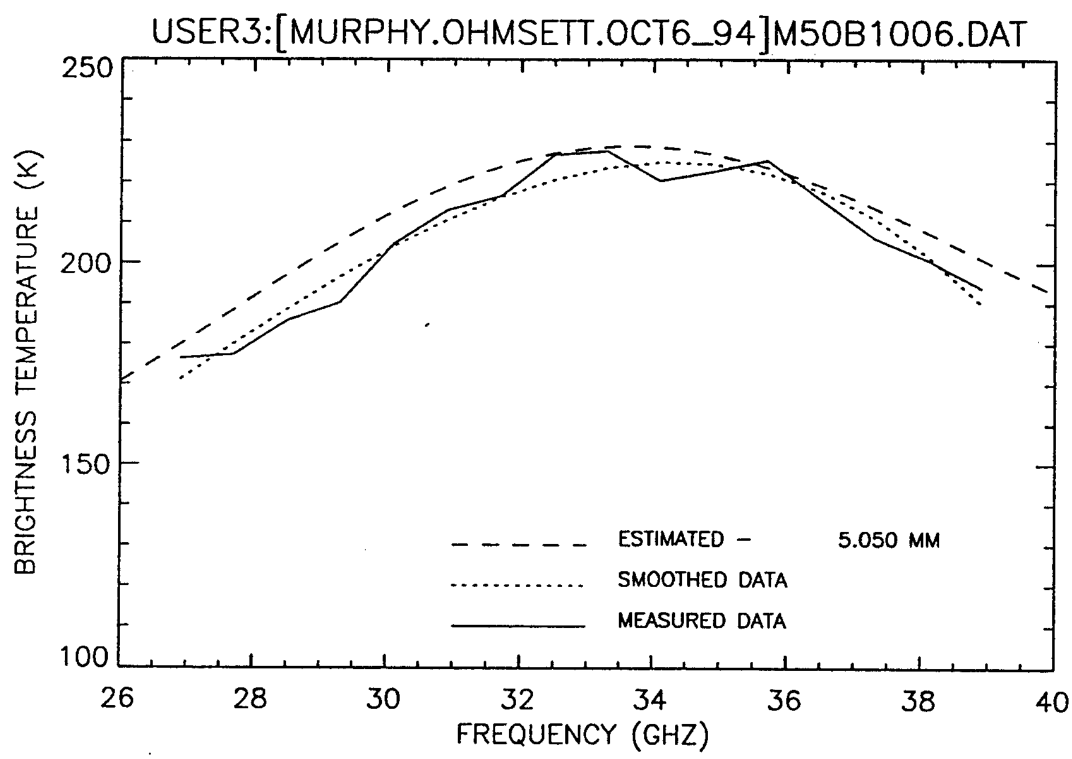

Figure A-54 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, 6 October 1994, Pass 2

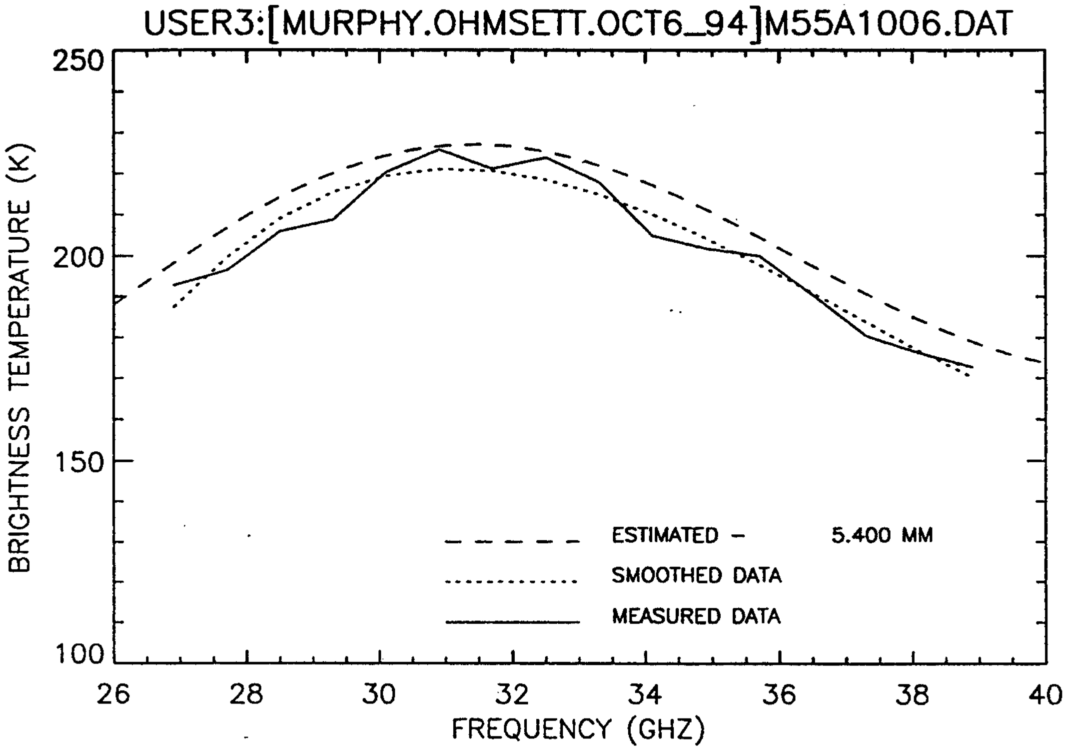

Figure A-55 T^B Versus Frequency Plot for 5.5 mm Uniform Oil Thickness, 6 October 1994, Pass 1

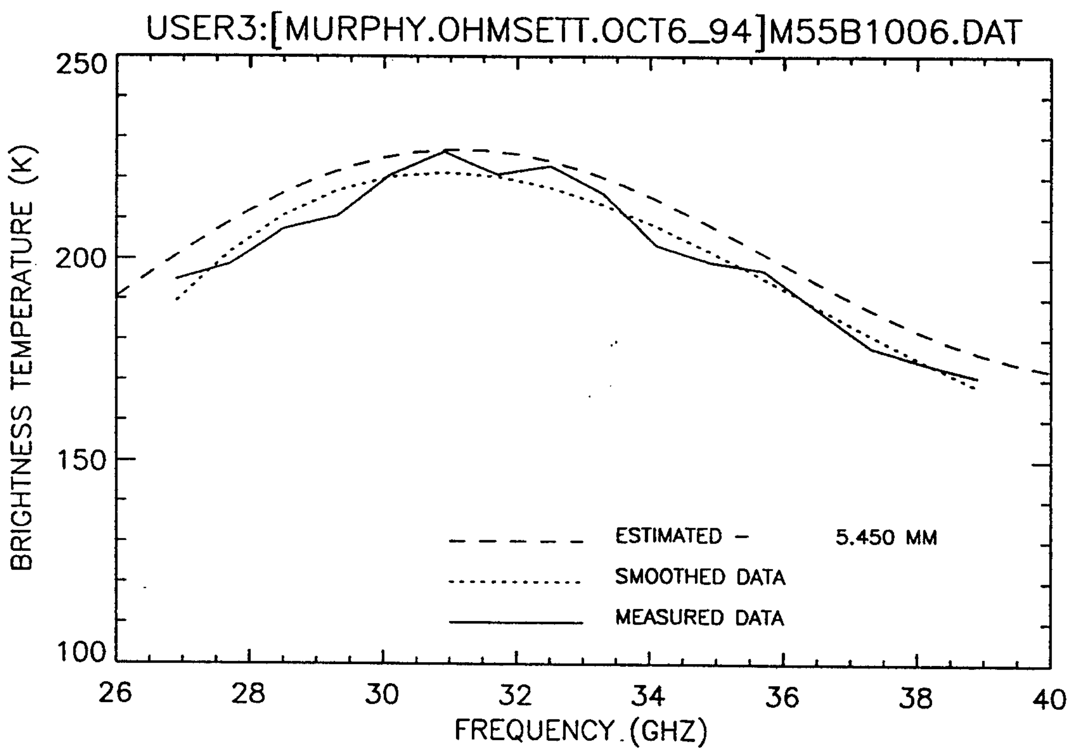

Figure A-56 T^B Versus Frequency Plot for 5.5 mm Uniform Oil Thickness, 6 October 1994, Pass 2

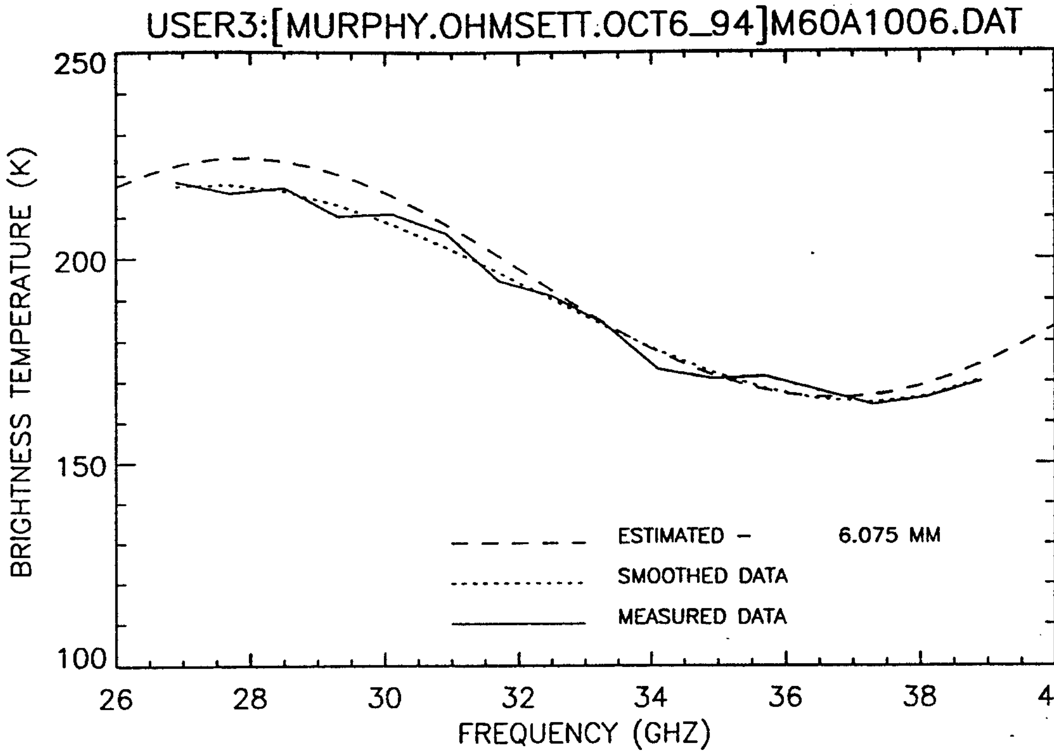

Figure A-57 T^B Versus Frequency Plot for 6.0 mm Uniform Oil Thickness, 6 October 1994, Pass 1

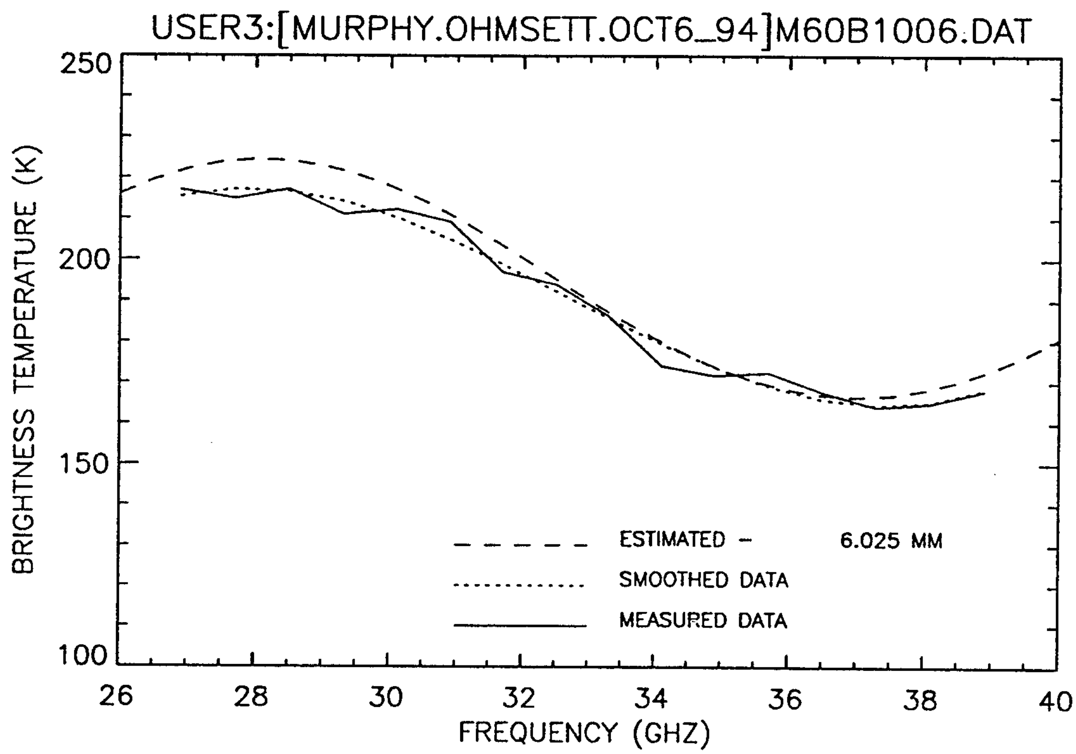

Figure A-58 T^B Versus Frequency Plot for 6.0 mm Uniform Oil Thickness, 6 October 1994, Pass 2

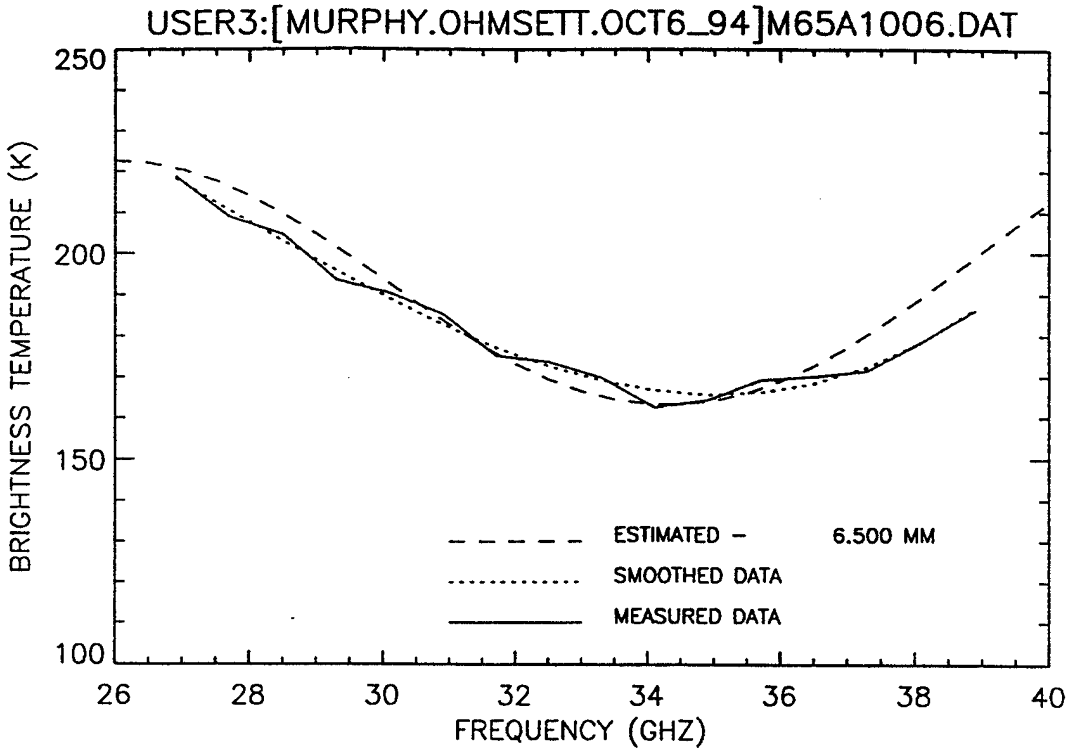

Figure A-59 T^B Versus Frequency Plot for 6.5 mm Uniform Oil Thickness, 6 October 1994, Pass 1

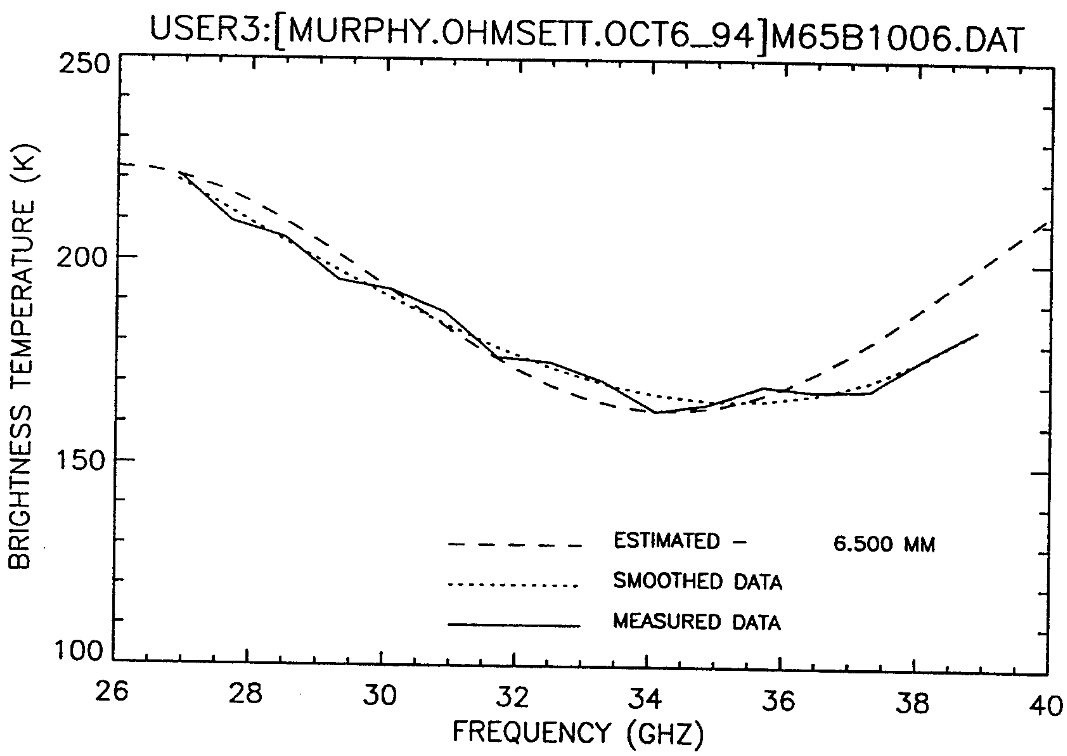

Figure A-60 T^B Versus Frequency Plot for 6.5 mm Uniform Oil Thickness, 6 October 1994, Pass 2

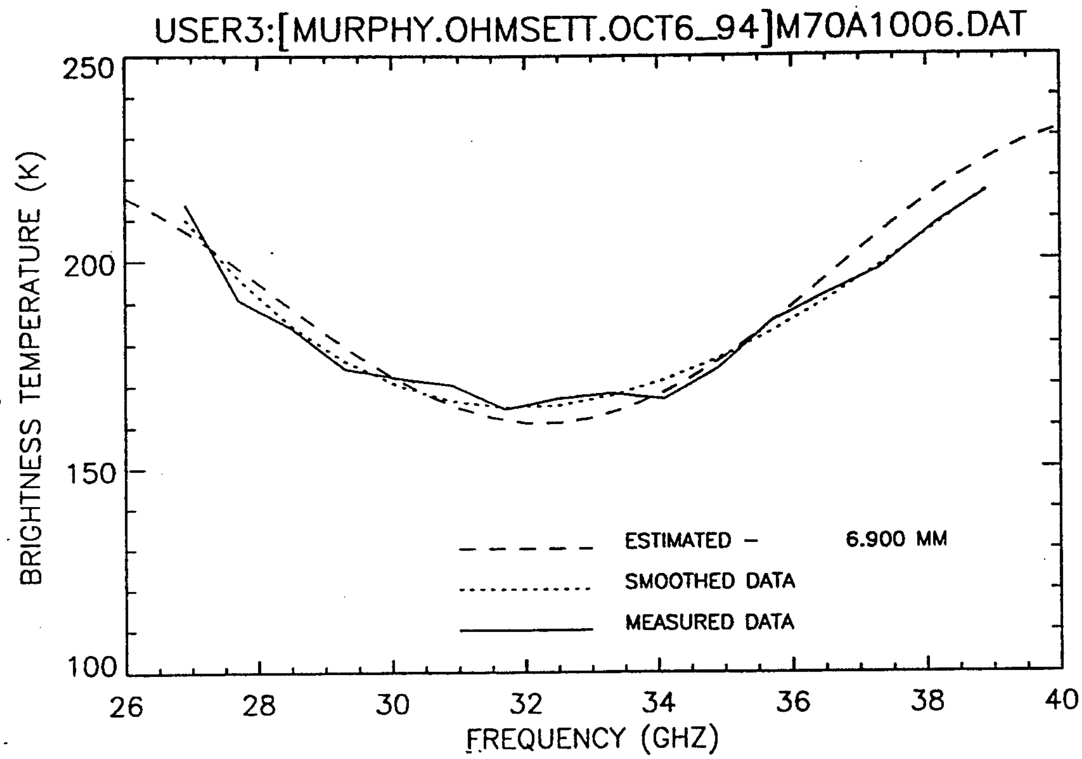

Figure A-61 T^B Versus Frequency Plot for 7.0 mm Uniform Oil Thickness, 6 October 1994, Pass 1

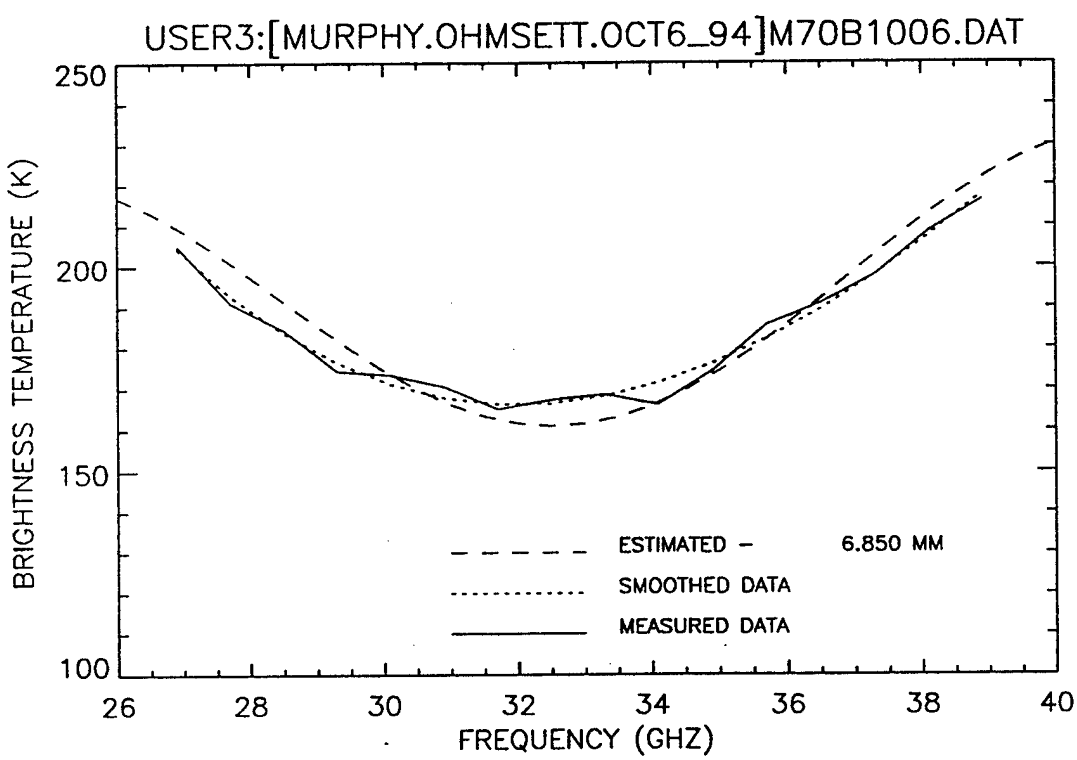

Figure A-62 T^B Versus Frequency Plot for 7.0 mm Uniform Oil Thickness,

6 October 1994, Pass 2

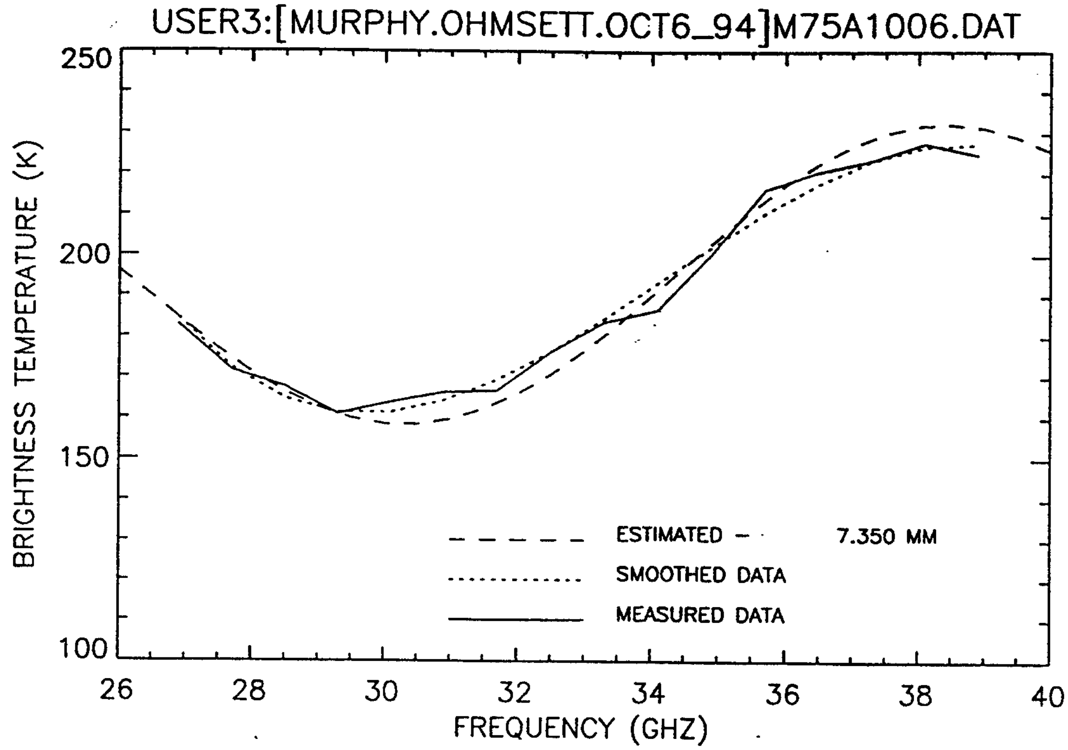

Figure A-63 T^B Versus Frequency Plot for 7.5 mm Uniform Oil Thickness, 6 October 1994, Pass 1

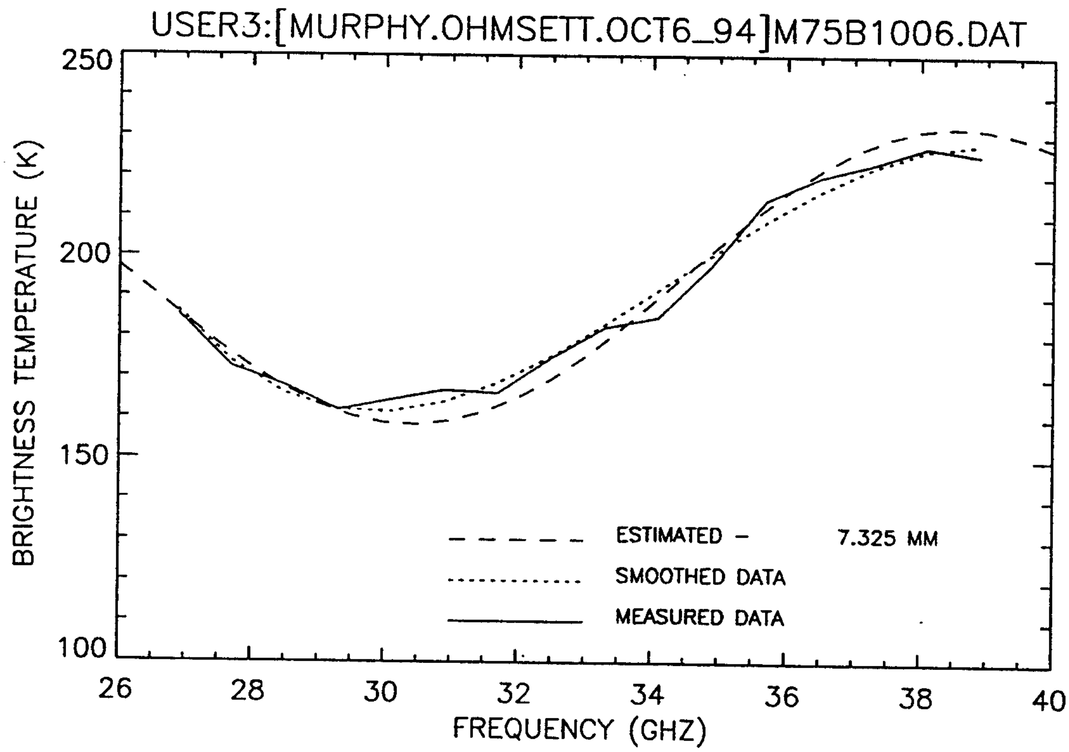

Figure A-64 T^B Versus Frequency Plot for 7.5 mm Uniform Oil Thickness, 6 October 1994, Pass 2

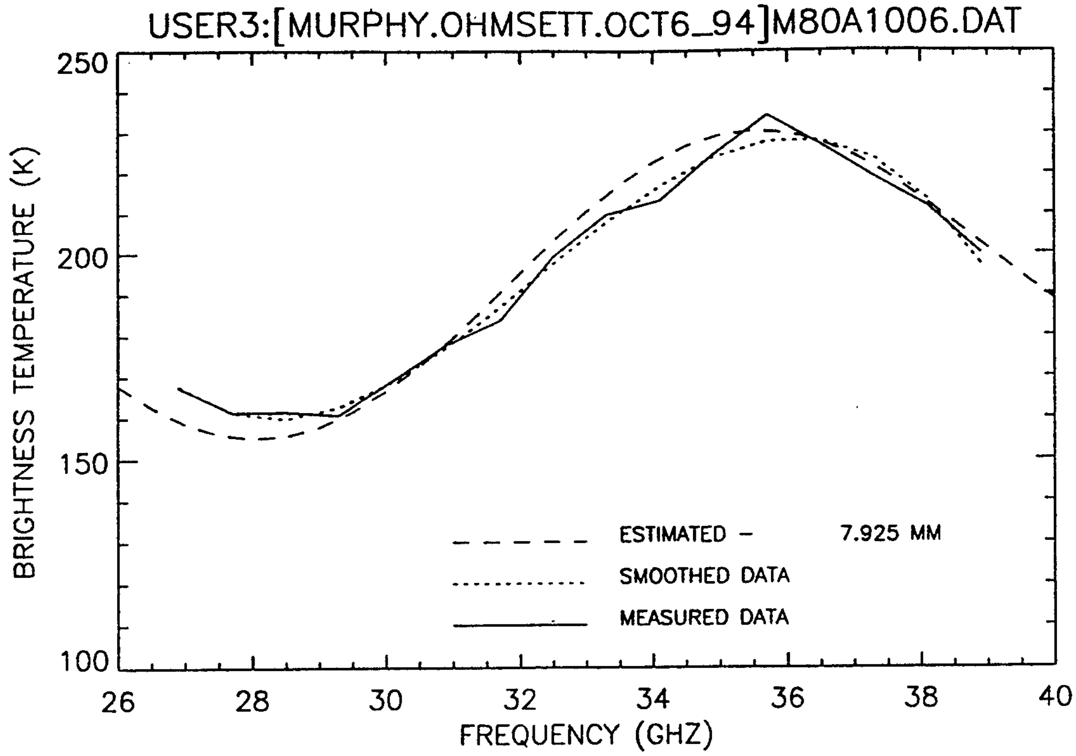

Figure A-65 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, 6 October 1994, Pass 1

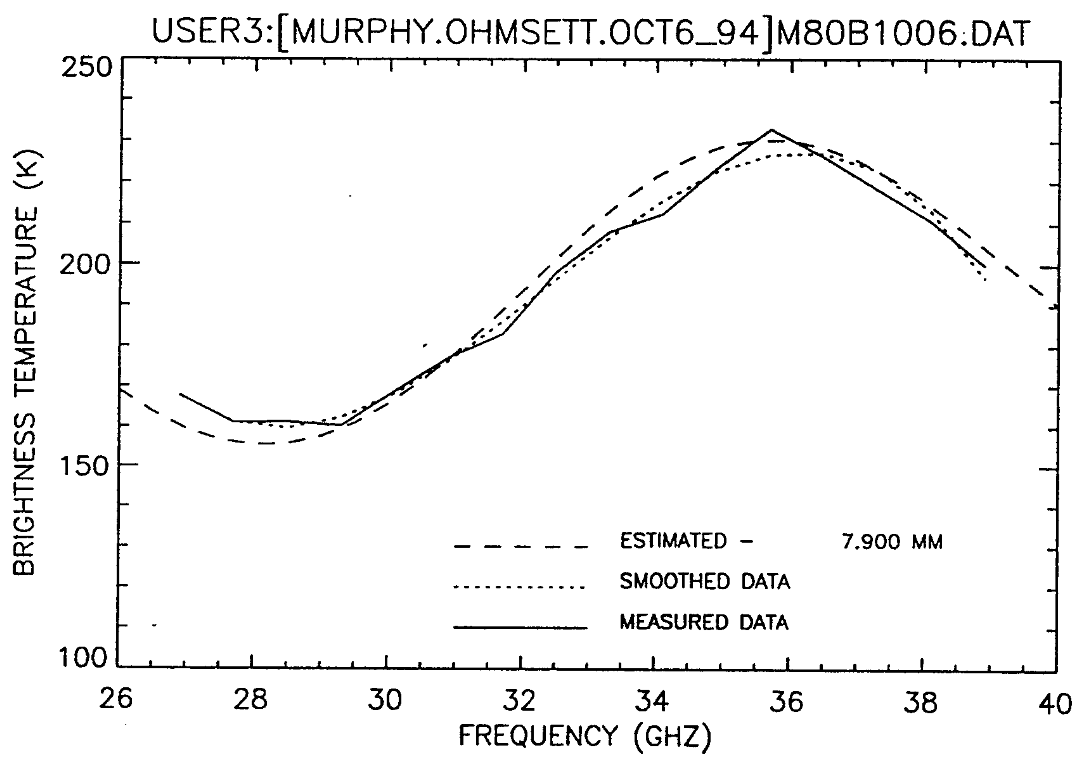

Figure A-66 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, 6 October 1994, Pass 2

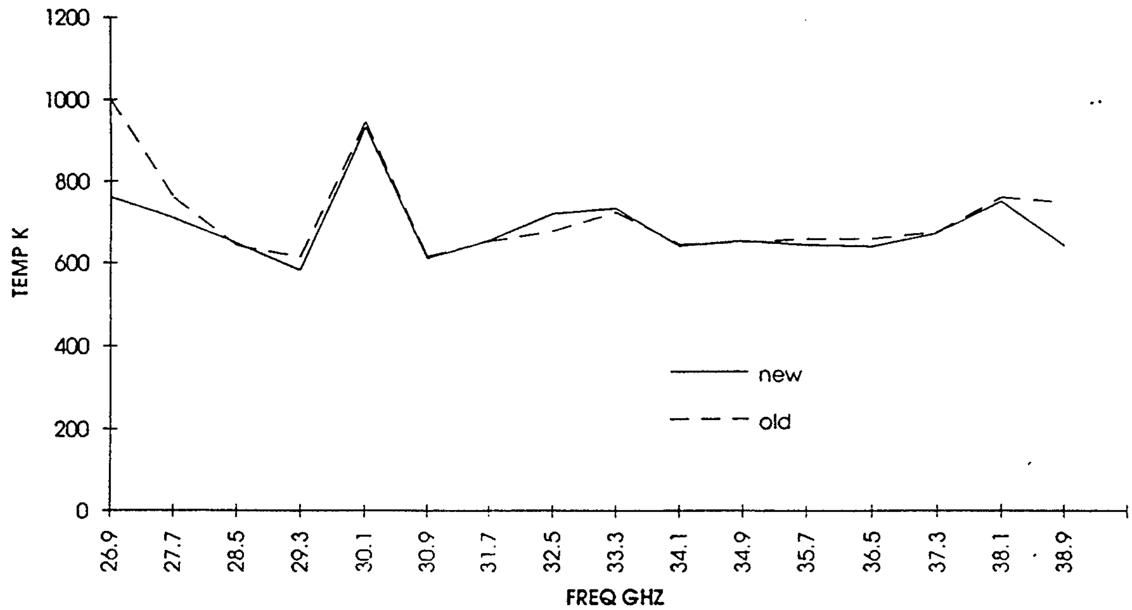

Figure A-67 Receiver Noise Comparison

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APPENDIX B

BRIGHTNESS TEMPERATURE VERSUS FREQUENCY PLOTS FROM OHMSETT ON-SITE TESTS

The frequency scanning radiometer was tested after transport to the OHMSETT facility to verify that the instrument was operating properly on-site. This testing was performed on the main equipment bridge. Validation tests were conducted on 11 and 12 October 1994 using RECCO 60 oil. Measurements on 11 October 1994 were conducted using the small laboratory-constructed calibrated test tank, with oil thicknesses of 0.0, 0.5, 1.0, 2.0, 3.0, and 6.0 mm. Measurements on 12 October used the laboratory test tank with a 6.0 mm oil thickness left over from the previous day, with and without a red dye added.

The file naming convention used for data files was cmmddttx.DAT, where c is a letter identifier for the test session (W = 11 Oct. 94, T = 12 Oct. 94, R = 12 Oct. 94 with red dye), mm is the month (October = 10), and dd is the day (11 or 12), tt is the thickness in tenths of a millimeter, x is the pass identifier. Thus R101260D.DAT was the fourth pass collected on dyed oil during the measurements of 12 October 1994 using an oil thickness of 6.0 mm.

The plots shown in this appendix, figures B-1 through B-20, are radiometric brightness temperature (T^B), expressed in Kelvin (K), as measured by the FSR, versus the measurement frequency in GHz. Under the current FSR software configuration, sixteen equally spaced points between 26.5 GHz and 40.0 GHz are sampled, with each sample period somewhat less than one second. These sixteen points are plotted as 'measured' points. For each data set, the oil thickness estimation algorithm, described in Chapter 4, is used to estimate an oil film thickness. This algorithm-derived estimate is displayed with the smoothed curve and the declared result plotted over the actual measured points. The data analyst can then either choose to accept the algorithm estimate, or manually select a curve that may be a better fit to the measured data.

A visual comparison of the measured curves versus the apparent best fit theoretical prediction produced the results in table B-1. The results of the oil thickness estimation algorithm yielded the results shown in Table B-2. Tables

B-3 through B-5 show the raw results of each curve fitting method used in the algorithm. The highlighted entries in tables B-2 through B-5 indicate estimates that were significantly different from the visual analysis resuls. Figures B-1 through B-20 show the raw FSR measurements plotted with the smoothed raw data curve and the theoretical T^B versus frequency curve for the visual analysis best fit estimate of oil thickness.

Table B-1

Visual Analysis Results of Oil Thickness For FSR On-Site Tests

Actual Thickness (mm)	11 October 94		
	Pass 1 (mm)	Pass 2 (mm)	Pass 3 (mm)
0.0	Reference	*	
0.5	0.475	0.425	
1.0	0.900	0.800	
2.0	2.075	1.900	1.950
3.0	3.075	2.975	
6.0	5.875	5.925	

12 October 94				
	Pass 1 (mm)	Pass 2 (mm)	Pass 3 (mm)	Pass 4 (mm)
6.0 - No Dye	5.975	5.925	6.175	
6.0 - Red Dye	Inconclusive (Note 1)	Inconclusive (Note 1)	6.125	6.200

* A slightly elevated T^B was reported relative to pass 1 because the FSR amplifiers had not yet reached thermal equilibrium relative to the reference pass. This demonstrates the importance of warming up the instrument and the dependence on a good water reference for measuring very thin oil films on water.

Note 1: After the introduction of the red dye into the oil, some air and water bubbles were observed on the surface of the oil. The bubbles were allowed to settle out, and new measurements were recorded approximately 2 hours later (passes 3 and 4). The bubbles on the surface of the oil created a quite different T^B versus frequency signature from the expected results.

Table B-2

Results of Oil Thickness Estimation Algorithm For FSR On-Site Tests

Actual Thickness (mm)	11 October 94		
	Pass 1 (mm)	Pass 2 (mm)	Pass 3 (mm)
0.0	Reference	*	
0.5	0.475	0.425	
1.0	0.900	0.800	
2.0	2.075	2.050	1.950
3.0	3.075	3.025	
6.0	5.875	5.925	

12 October 94				
	Pass 1 (mm)	Pass 2 (mm)	Pass 3 (mm)	Pass 4 (mm)
6.0 - No Dye	5.975	5.925	6.175	
6.0 - Red Dye	1.975	2.000	6.125	6.200

* A slightly elevated T^B was reported relative to pass 1 because the FSR amplifiers had not yet reached thermal equilibrium relative to the reference pass. This demonstrates the importance of warming up the instrument and the dependence on a good water reference for measuring very thin oil films on water.

Note 1: After the introduction of the red dye into the oil, some air and water bubbles were observed on the surface of the oil. The bubbles were allowed to settle out, and new measurements were recorded approximately 2 hours later (passes 3 and 4). The bubbles on the surface of the oil created a quite different T^B versus frequency signature from the expected results.

Table B-3

Results of Oil Thickness Estimation Algorithm For FSR On-Site Tests Using Only LMS

Actual Thickness (mm)	11 October 94		
	Pass 1 (mm)	Pass 2 (mm)	Pass 3 (mm)
0.0	Reference	*	
0.5	0.475	0.425	
1.0	0.900	0.800	
2.0	2.075	2.025	1.975
3.0	3.150	3.000	
6.0	5.925	5.925	

	12 October 94			
	Pass 1 (mm)	Pass 2 (mm)	Pass 3 (mm)	Pass 4 (mm)
6.0 - No Dye	5.950	5.925	6.200	
6.0 - Red Dye	1.975	2.000	6.125	6.200

* A slightly elevated T^B was reported relative to pass 1 because the FSR amplifiers had not yet reached thermal equilibrium relative to the reference pass. This demonstrates the importance of warming up the instrument and the dependence on a good water reference for measuring very thin oil films on water.

Table B-4

Results of Oil Thickness Estimation Algorithm For FSR On-Site Tests Using Only Correlation

Actual Thickness (mm)	11 October 94			
	Pass 1 (mm)	Pass 2 (mm)	Pass 3 (mm)	
0.0	Reference	*		
0.5	0.550	4.175		
1.0	4.275	4.325		
2.0	1.925	1.850	1.950	
3.0	3.000	2.825		
6.0	5.850	5.925		
	12 October 94			
	Pass 1 (mm)	Pass 2 (mm)	Pass 3 (mm)	Pass 4 (mm)
6.0 - No Dye	6.000	5.925	6.175	
6.0 - Red Dye	6.250	6.300	6.150	6.200

* A slightly elevated T^B was reported relative to pass 1 because the FSR amplifiers had not yet reached thermal equilibrium relative to the reference pass. This demonstrates the importance of warming up the instrument and the dependence on a good water reference for measuring very thin oil films on water.

Table B-5

Results of Oil Thickness Estimation Algorithm For FSR On-Site Tests Using Only Mean/Slope

Actual Thickness (mm)	11 October 94		
	Pass 1 (mm)	Pass 2 (mm)	Pass 3 (mm)
0.0	Reference	*	
0.5	0.500	4.250	
1.0	0.900	0.800	
2.0	2.100	2.100	2.000
3.0	3.300	3.075	
6.0	2.600	2.525	

12 October 94				
	Pass 1 (mm)	Pass 2 (mm)	Pass 3 (mm)	Pass 4 (mm)
6.0 - No Dye	2.475	2.525	2.675	
6.0 - Red Dye	1.700	1.725	2.575	2.600

* A slightly elevated T^B was reported relative to pass 1 because the FSR amplifiers had not yet reached thermal equilibrium relative to the reference pass. This demonstrates the importance of warming up the instrument and the dependence on a good water reference for measuring very thin oil films on water.

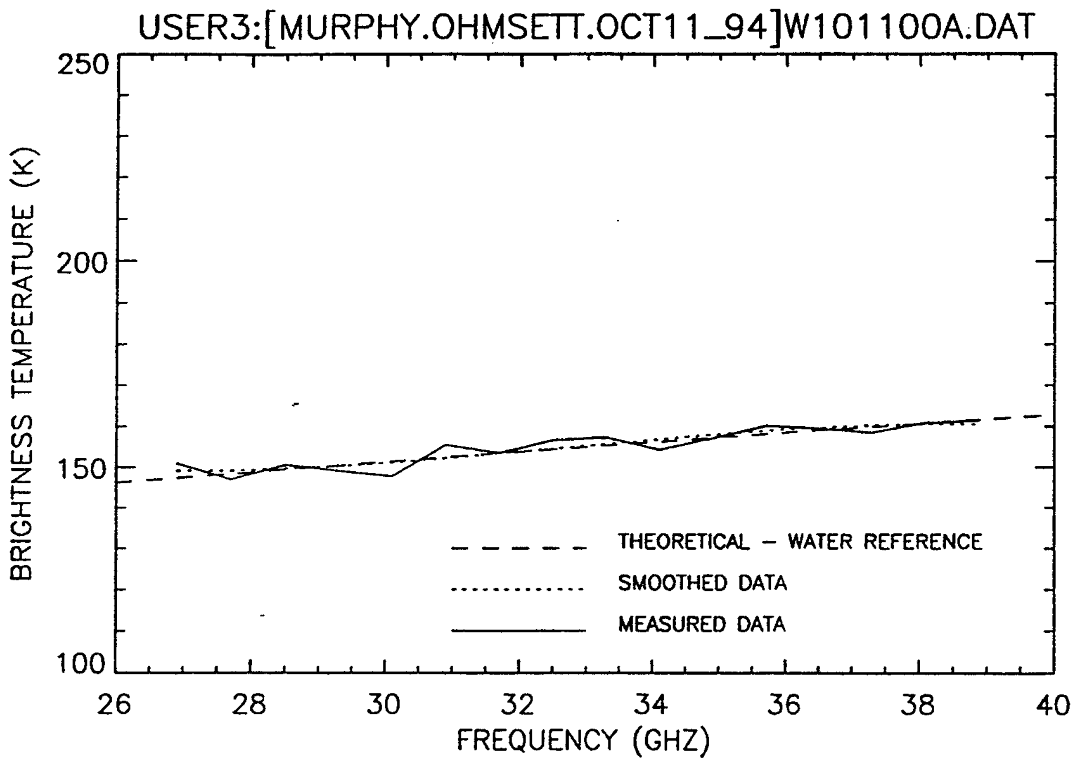

Figure B-1 T^B Versus Frequency Plot for Background Water, 11 October 1994, Pass 1

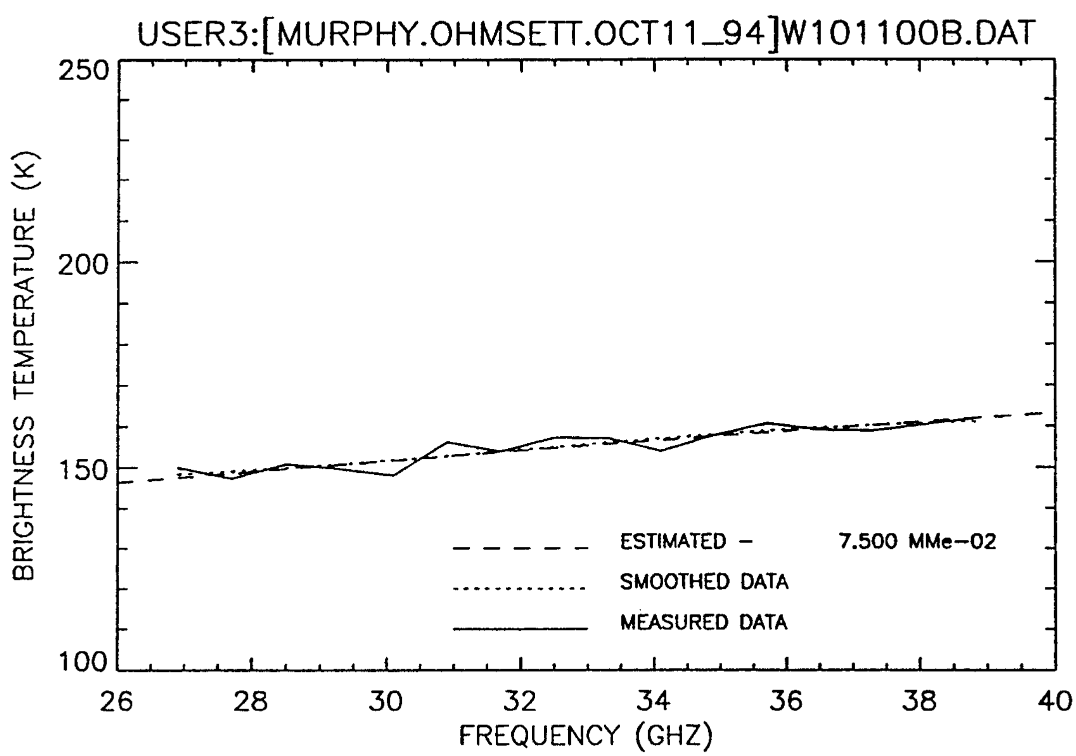

Figure B-2 T^B Versus Frequency Plot for Background Water, 11 October 1994, Pass 2

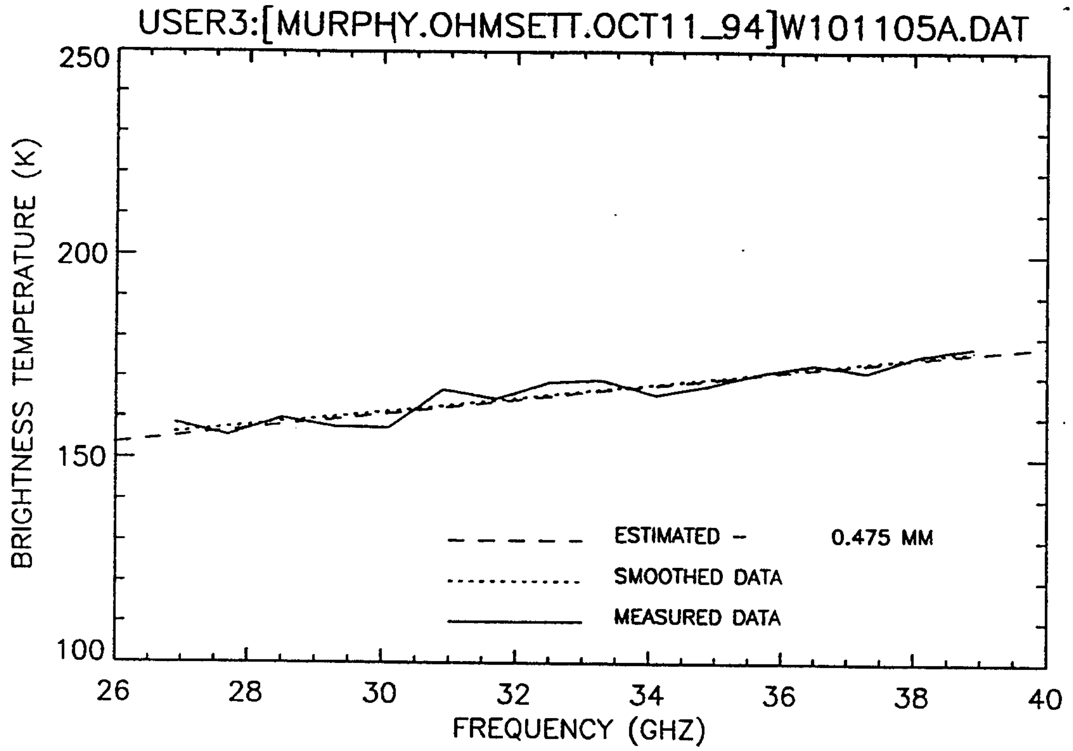

Figure B-3 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, 11 October 1994, Pass 1

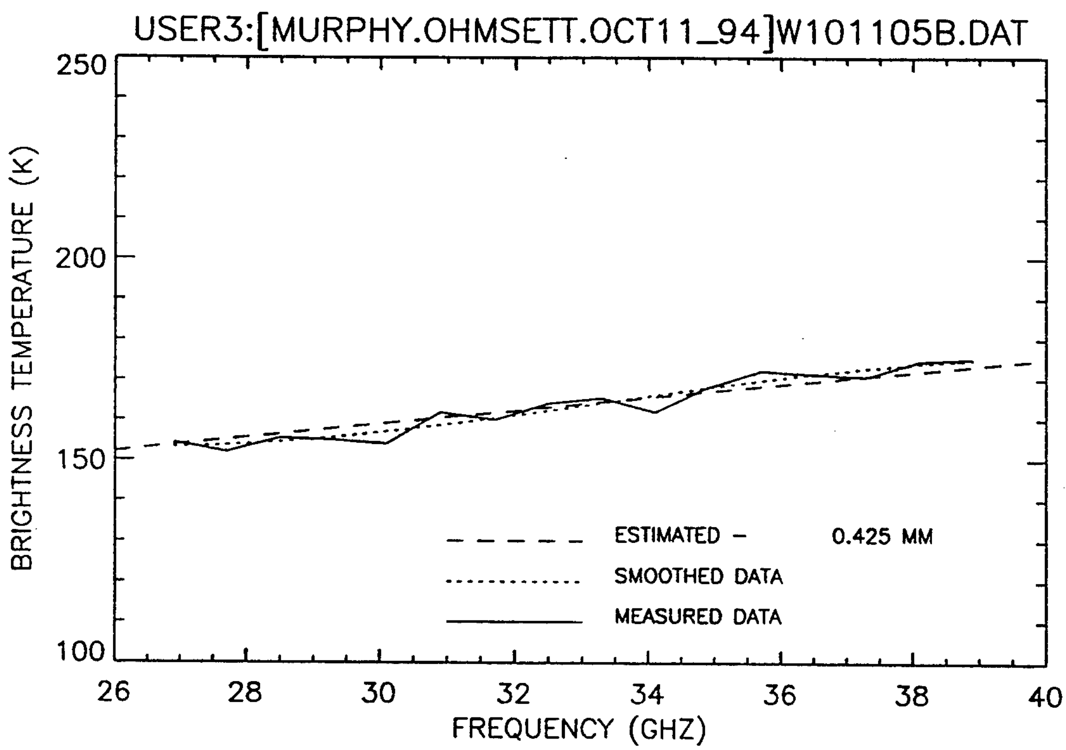

Figure B-4 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, 11 October 1994, Pass 2

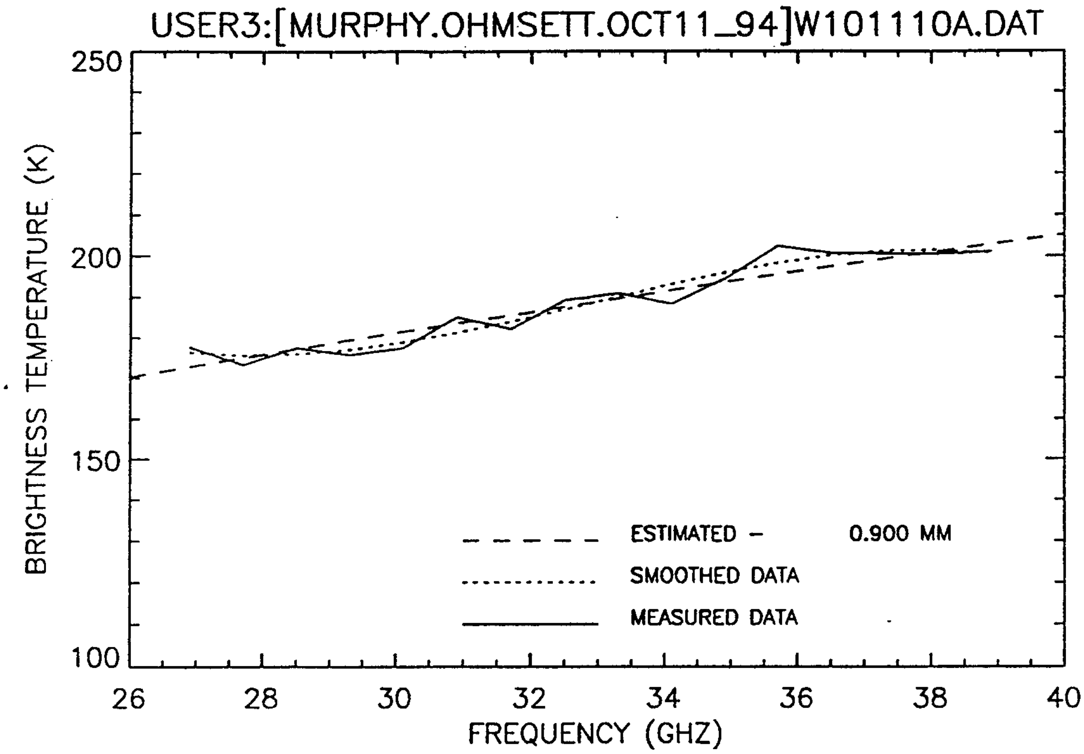

Figure B-5 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, 11 October 1994, Pass 1

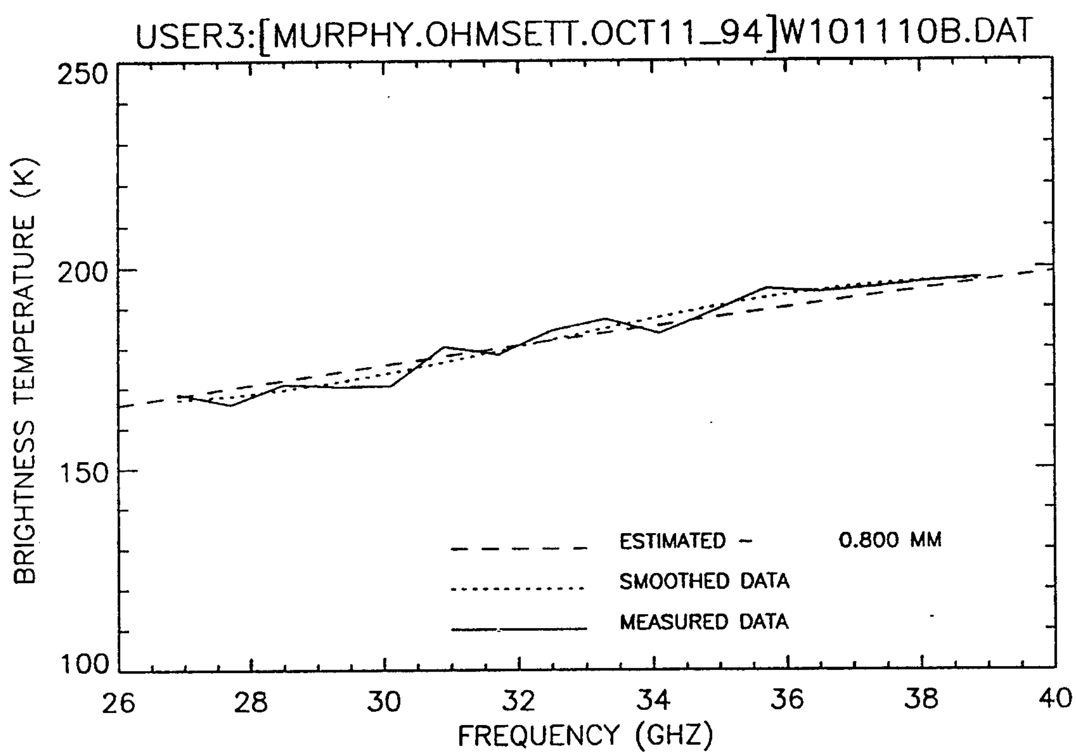

Figure B-6 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, 11 October 1994, Pass 2

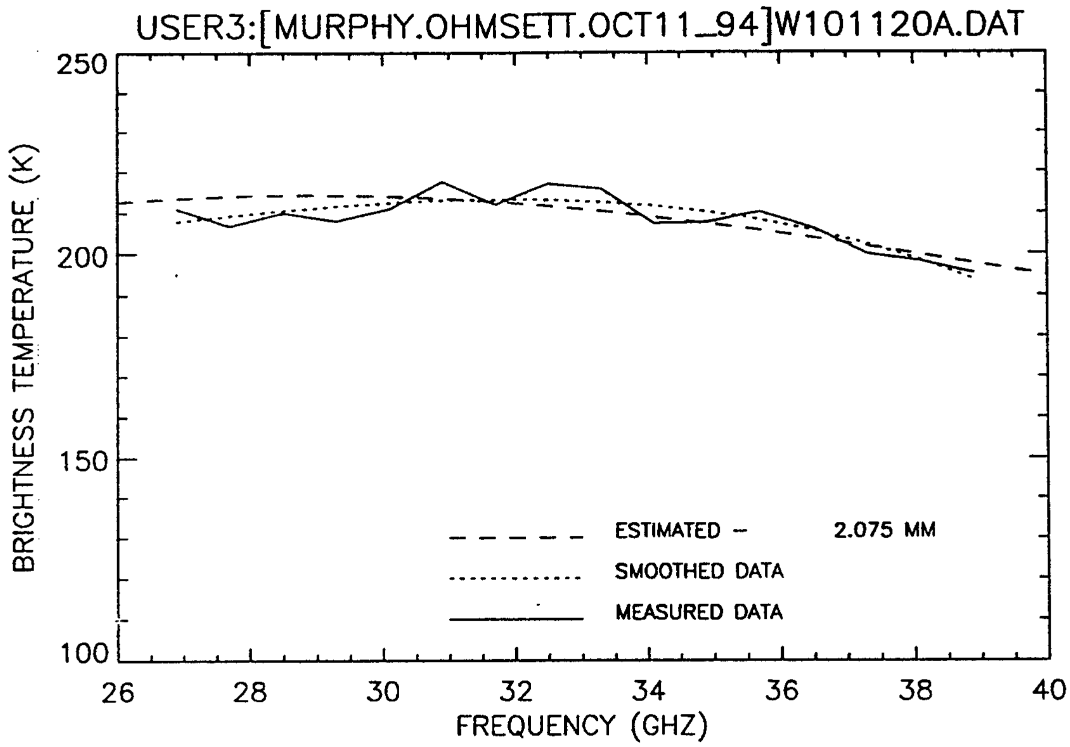

Figure B-7 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, 11 October 1994, Pass 1

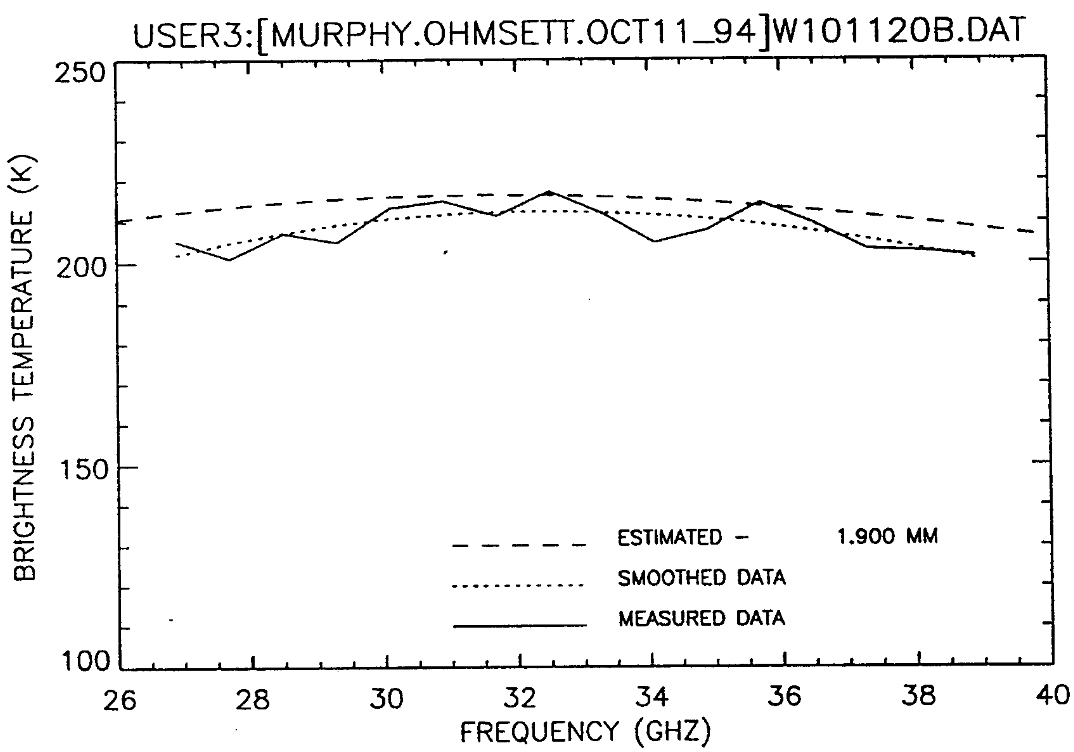

Figure B-8 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, 11 October 1994, Pass 2

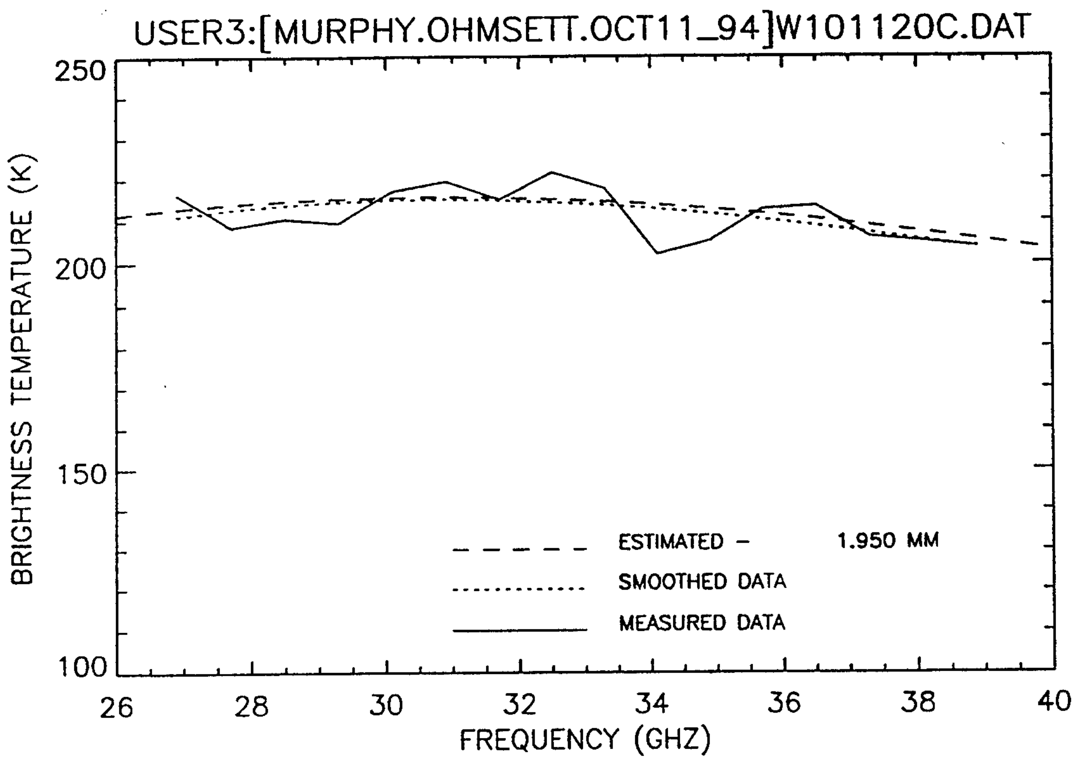

Figure B-9 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, 11 October 1994, Pass 3

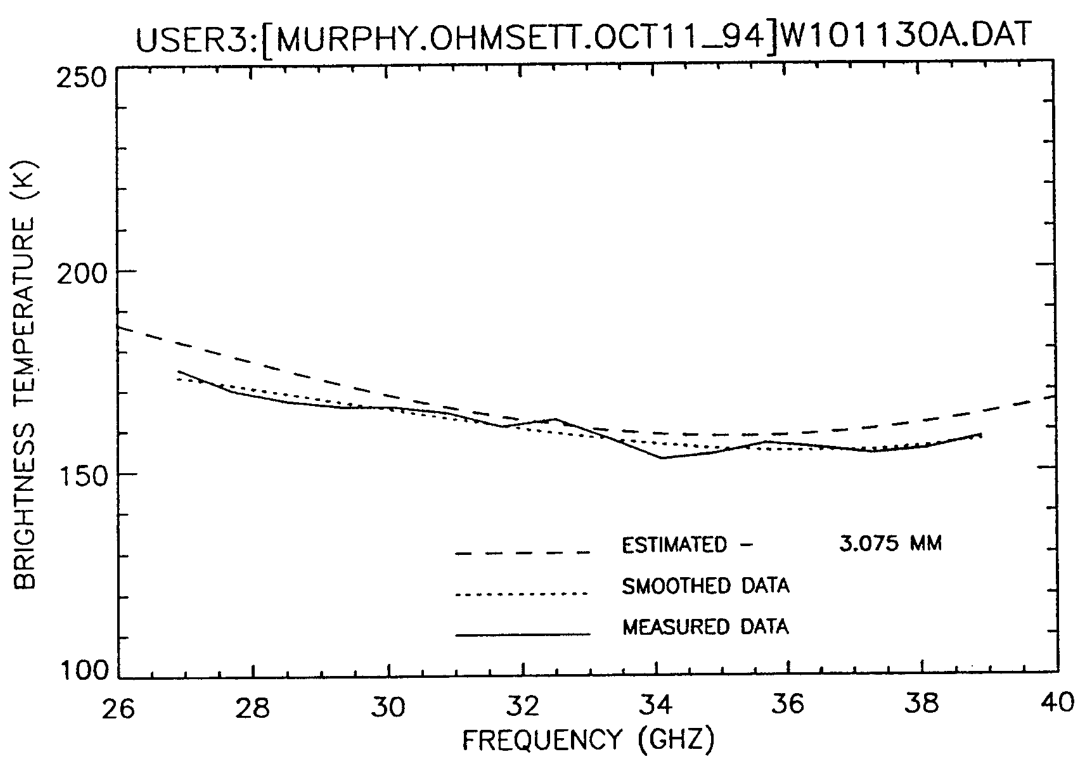

Figure B-10 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, 11 October 1994, Pass 1

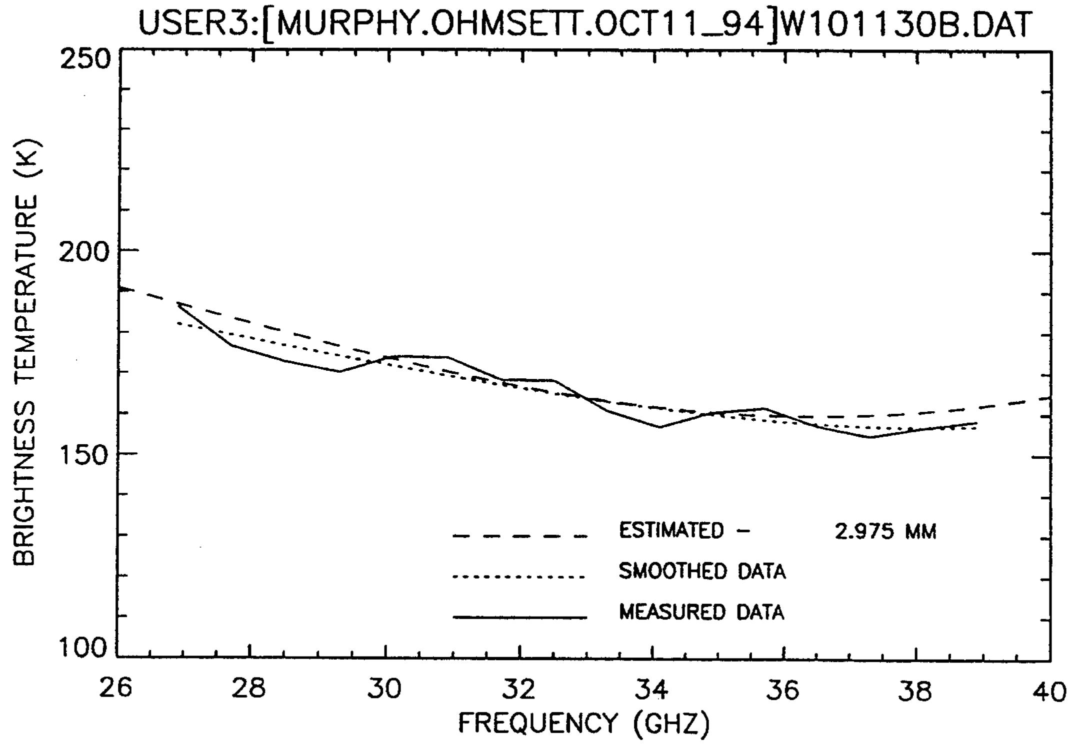

Figure B-11 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, 11 October 1994, Pass 2

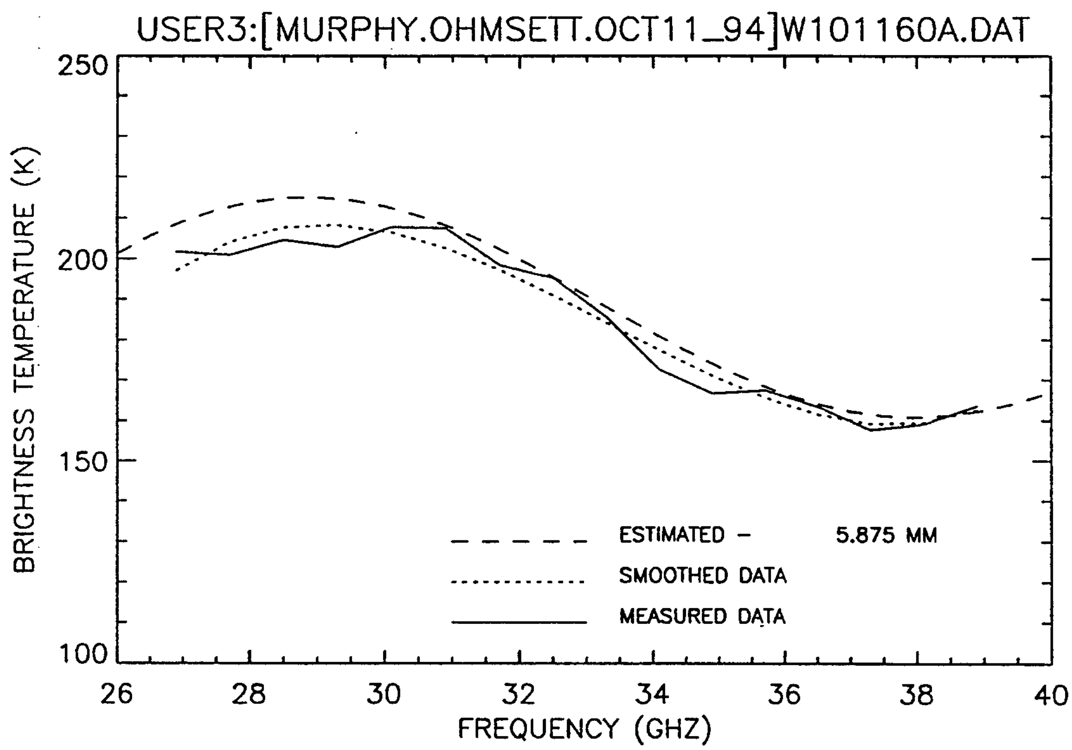

Figure B-12 T^B Versus Frequency Plot for 6.0 mm Uniform Oil Thickness, 11 October 1994, Pass 1

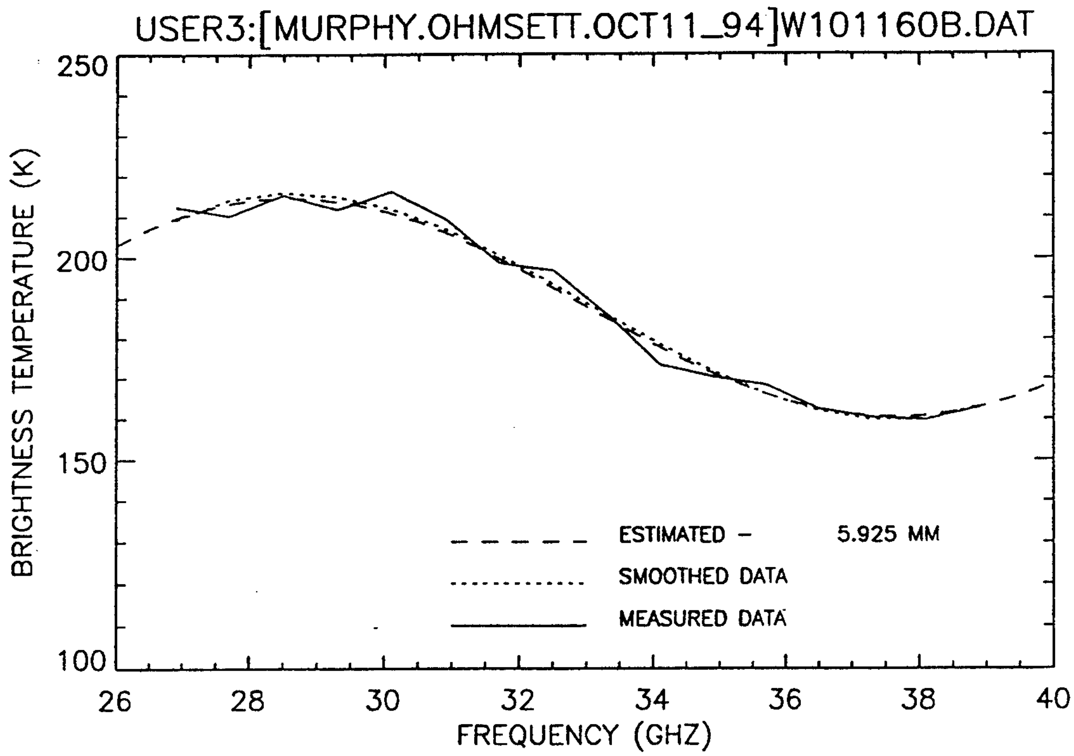

Figure B-13 T^B Versus Frequency Plot for 6.0 mm Uniform Oil Thickness, 11 October 1994, Pass 2

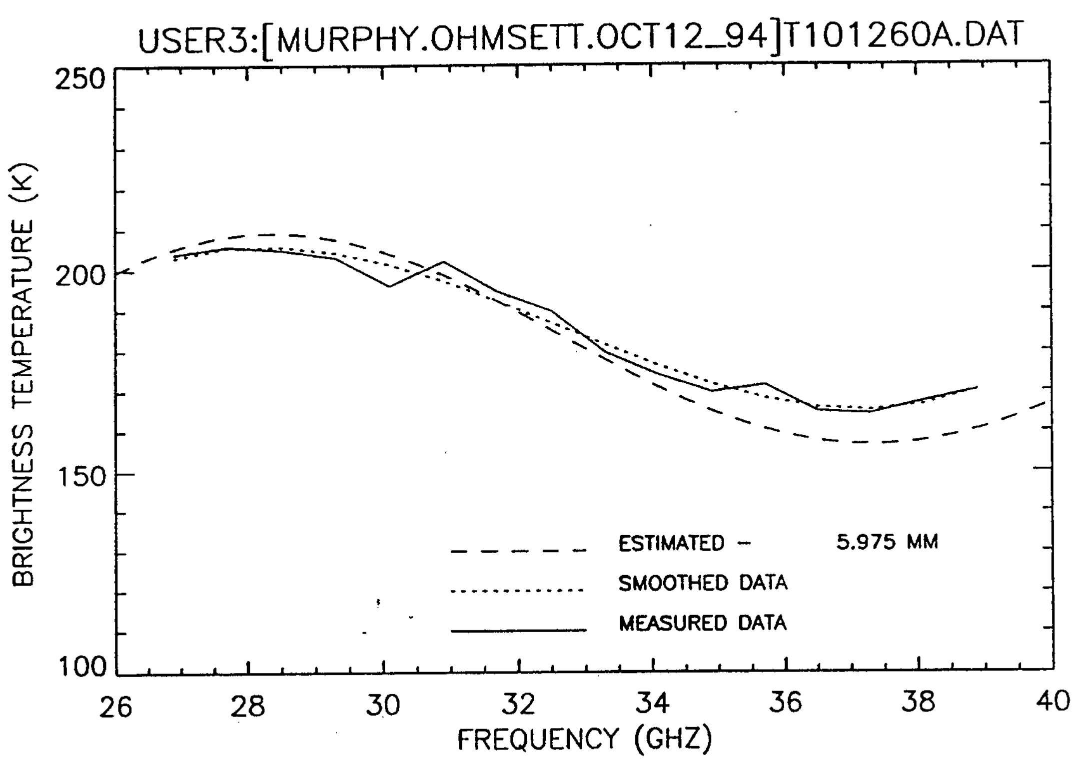

Figure B-14 T^B Versus Frequency Plot for 6.0 mm Uniform Oil Thickness, 12 October 1994, Pass 1, Before Addition of Red Dye

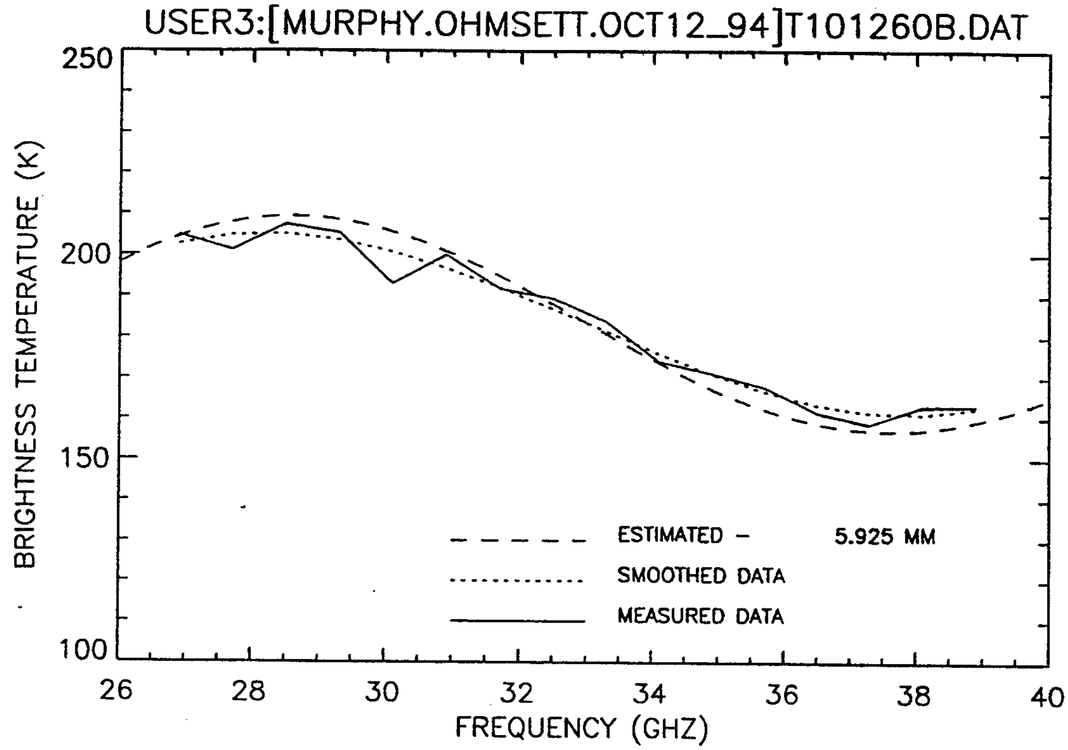

Figure B-15 T^B Versus Frequency Plot for 6.0 mm Uniform Oil Thickness, 12 October 1994, Pass 2, Before Addition of Red Dye

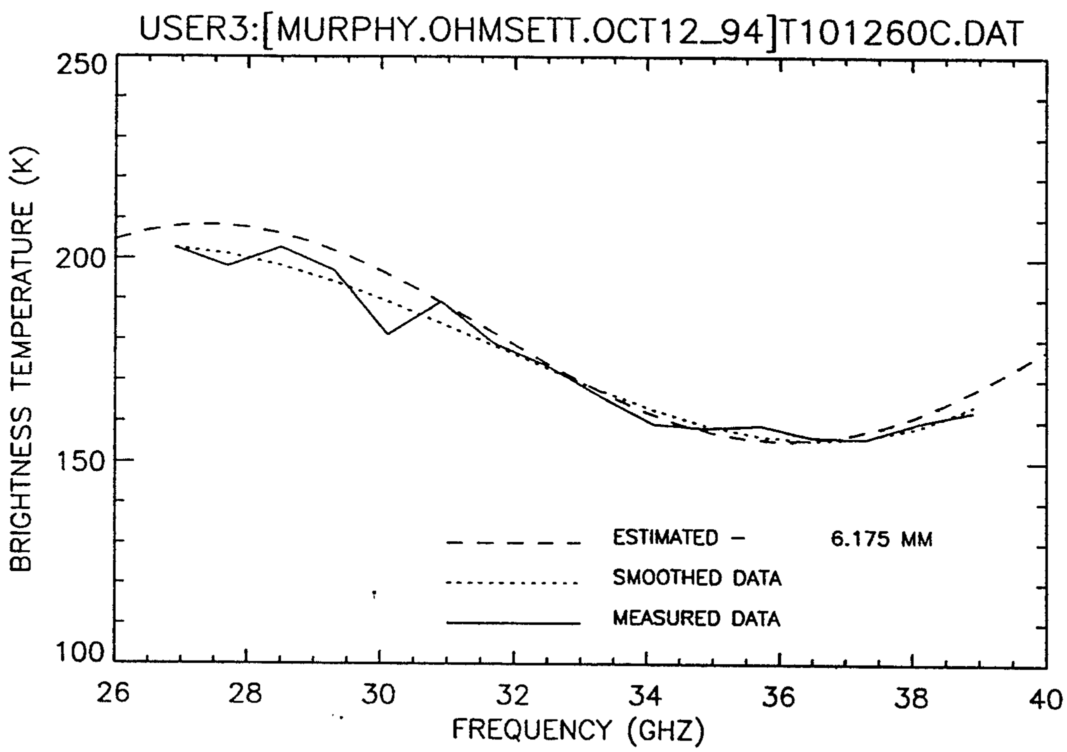

Figure B-16 T^B Versus Frequency Plot for 6.0 mm Uniform Oil Thickness, 12 October 1994, Pass 3, Before Addition of Red Dye

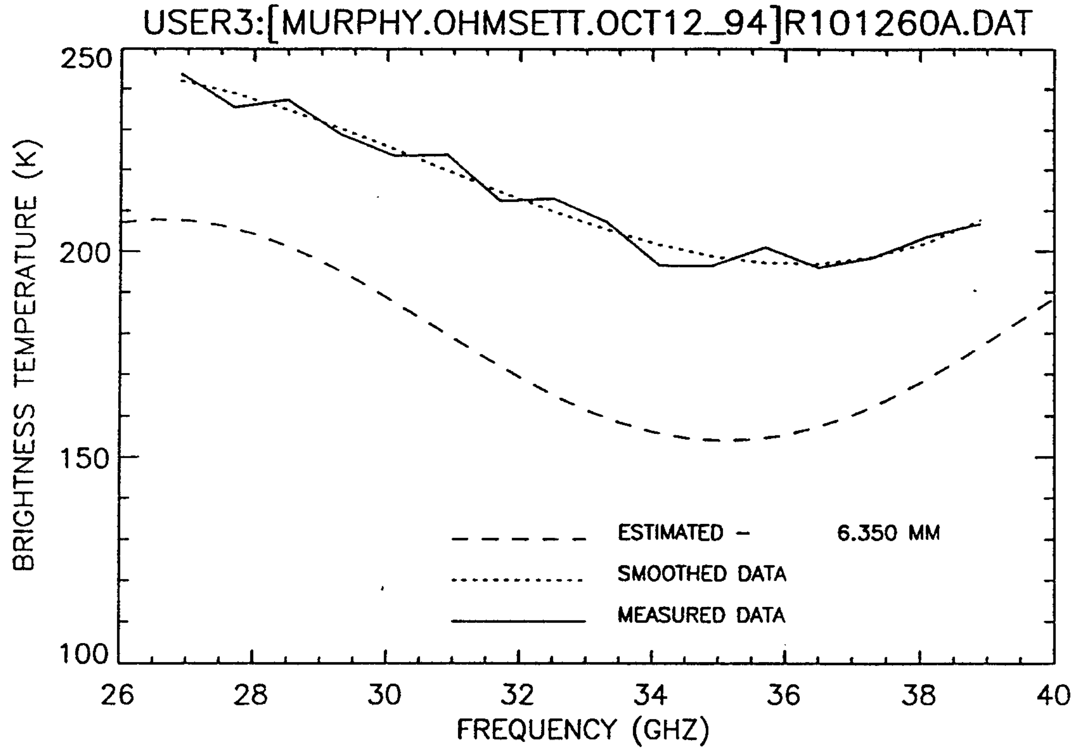

Figure B-17 T^B Versus Frequency Plot for 6.0 mm Uniform Oil Thickness, 12 October 1994, Pass 1, After Addition of Red Dye

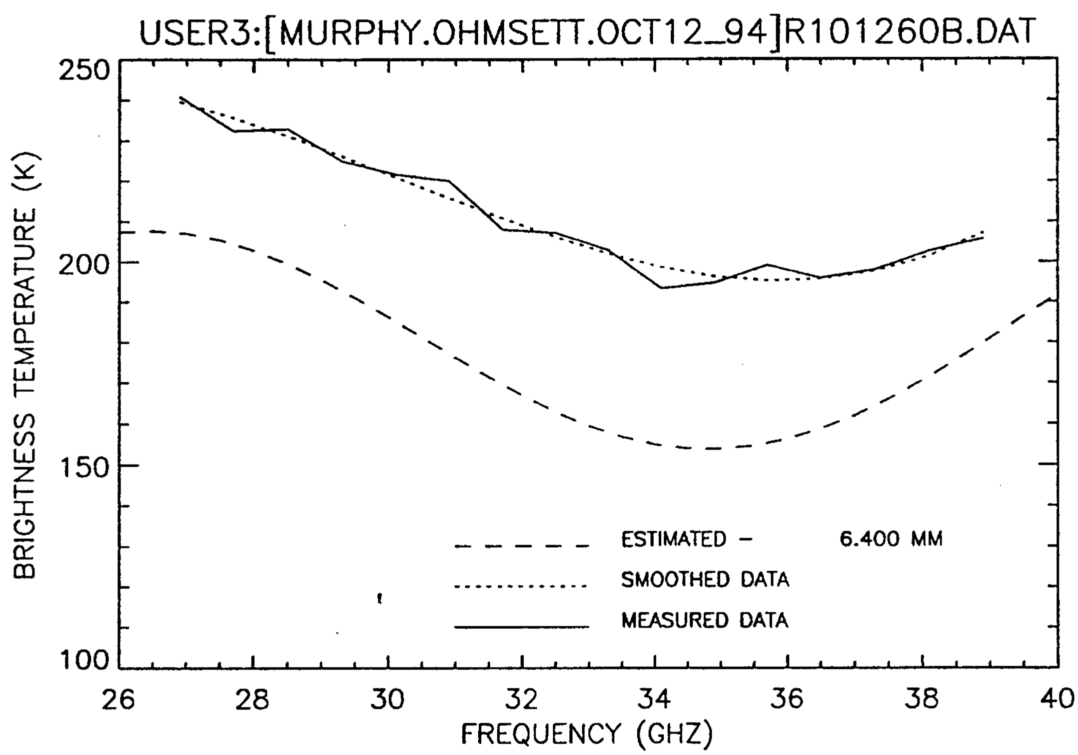

Figure B-18 T^B Versus Frequency Plot for 6.0 mm Uniform Oil Thickness, 12 October 1994, Pass 2, After Addition of Red Dye

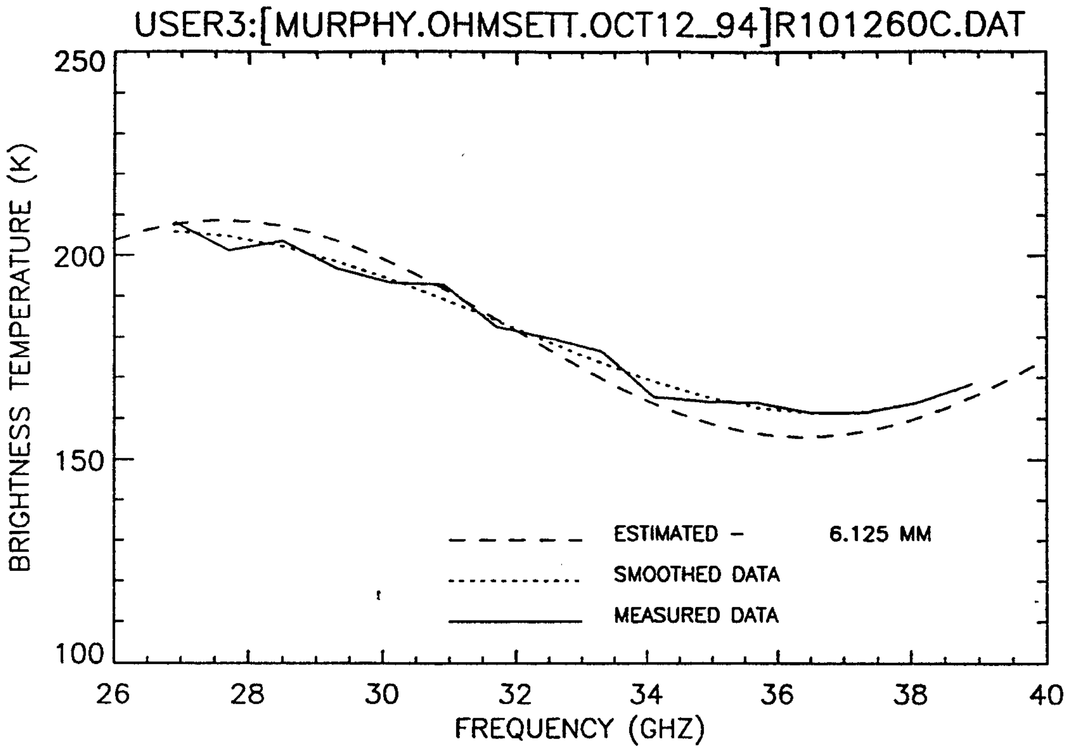

Figure B-19 T^B Versus Frequency Plot for 6.0 mm Uniform Oil Thickness, 12 October 1994, Pass 3, After 2-Hour Settling Time Since Dye Addition

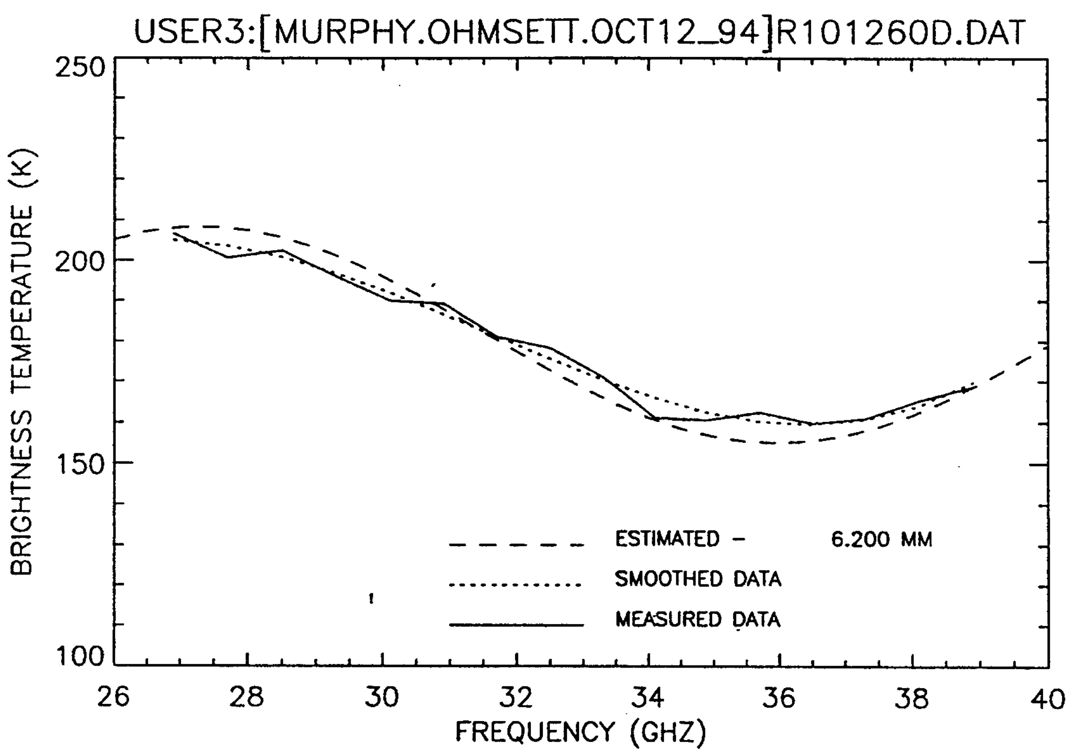

Figure B-20 T^B Versus Frequency Plot for 6.0 mm Uniform Oil Thickness, 12 October 1994, Pass 4, After 2-Hour Settling Time Since Dye Addition

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APPENDIX C

BRIGHTNESS TEMPERATURE VERSUS FREQUENCY PLOTS FROM OHMSETT DRY RUN TESTS

The frequency scanning radiometer was set up at the OHMSETT facility on the main equipment bridge with the oil pools in the radiometer antenna field of view. Dry run tests were conducted on 11 and 12 October 1994 Measurements were conducted using RECCO 60 oil and dyed diesel oil, under a preliminary set of wave conditions.

The file naming convention used for data files was cttxmmdd.DAT, where c is a letter identifier for the test session (B = 11 Oct. 94 - calm water measurements of RECCO 60 oil, C = 12 Oct. 94 - water background measurements, D = 12 Oct. 94 - uniform thickness measurements of 5.0 mm RECCO 60, E = 12 Oct. 94 - dyed diesel from 0.0 to 5.0 mm and 8.0 mm, F = 12 Oct. 94 - dyed diesel in small waves, G = 12 Oct. 94 - dyed diesel in medium waves), tt is the thickness in tenths of a millimeter, x is the pass identifier, mm is the month (October = 10), and dd is the day. Thus F101280C.DAT was the third pass collected on 12 October 1994 using a thickness of 8.0 mm oil in small wave conditions.

The plots shown in this appendix are radiometric brightness temperature (T^B), expressed in Kelvin (K), as measured by the FSR, versus the measurement frequency in GHz. Under the current FSR software configuration, sixteen equally spaced points between 26.5 GHz and 40.0 GHz are sampled, with each sample period somewhat less than one second. These sixteen points are plotted as 'measured' points. For each data set, the oil thickness estimation algorithm, described in Chapter 4, is used to estimate an oil film thickness. This algorithm-derived estimate is displayed with the smoothed curve and the declared result plotted over the actual measured points. The data analyst can then either choose to accept the algorithm estimate, or manually select a curve that may be a better fit to the measured data.

The plots in this appendix are arranged by test session. At the beginning of each test session data set, comments are provided for each measurement concerning the fit of the algorithm estimate and the analyst's choice for each curve's best fit.

When viewing the plots, it is important to understand that the figure titles cite only the target oil thickness value within the test pool being viewed. As described in chapter 3, the actual thickness of oil being viewed by the FSR at any given moment could vary substantially from this target value.

B101100A - The algorithm-based estimate curve is plotted slightly above the water reference.

B101100B - This is the water reference that was chosen for use with this set of measurements.

B101110A - This curve has a somewhat flat response with a fair match to 0.725 mm oil thickness.

B101120A -This curve has a flat response. It is a poor match to the algorithm estimate of 0.975 mm. The curve does not exhibit a 2.0 mm characteristic. The result is inconclusive.

B101130A - This curve exhibits a flat response. It is a poor match to the algorithm estimate of 0.825 mm curve. The curve does not exhibit a 3.0 mm characteristic. The result is inconclusive.

After the B101130A measurement, the bridge was moved so that the FSR could measure an area that visually appeared to have thicker oil.

B101130B - This curve exhibits a flat response. It is a poor match to the algorithm estimate of 1.050 mm. The curve does not exhibit a 3.0 mm characteristic. The result is inconclusive.

B101140A -This curve is a poor match to the algorithm estimate of 1.775 mm. It does not exhibit a 4.0 mm characteristic. The location of the peak and the shape of curve matches a 5.0 mm prediction, which corresponded to the correlation result shown on the plot.

B101140B - This curve is a poor match to the algorithm estimate of 2.4 mm. The curve does not exhibit a 4.0 mm characteristic. The location of the null and the shape of curve matches a 6.200 mm prediction, which corresponded to the correlation result shown on the plot.

B101140C - This curve is a poor match to the algorithm estimate of 0.95 mm. This curve exhibits a shape characteristic that has a null near 31 GHz which is a 3.4 - 3.6 mm characteristic. This corresponds well with the correlation result shown on the plot.

B101140D -This curve is a poor match to the algorithm estimate of 1.15 mm. The curve exhibits an up slope characteristic, similar to a 4.0 mm curve, however a null appears near 29 GHz. This is more consistent with the 3.8 mm characteristic.

B101150A - This curve is a poor match to the algorithm estimate of 2.475 mm. The curve does not have a peak centered near 34 GHz, which is a 5.0 mm trait. It exhibits a down slope, peak and null characteristic similar to a 6.3 mm curve, which corresponds to the correlation result shown on the plot.

B101150B - This curve is a poor match to the algorithm estimate of 2.375 mm. It does not have a peak centered near 34 GHz, which is a 5.0 mm trait. The curve exhibits a down slope and null characteristic similar to a 6.0 mm curve. This corresponds to the LMS and correlation result shown on the plot.

B101150C - This curve is a good match to the algorithm estimate of 5.75 mm.

B101150D - This curve is a poor match to the algorithm estimate of 2.4 mm. It does not have a peak centered near 34 GHz, which is a 5.0 mm trait. The curve exhibits a down slope and null characteristic similar to a 6.35 mm curve. This corresponds to the LMS and correlation result shown on the plot.

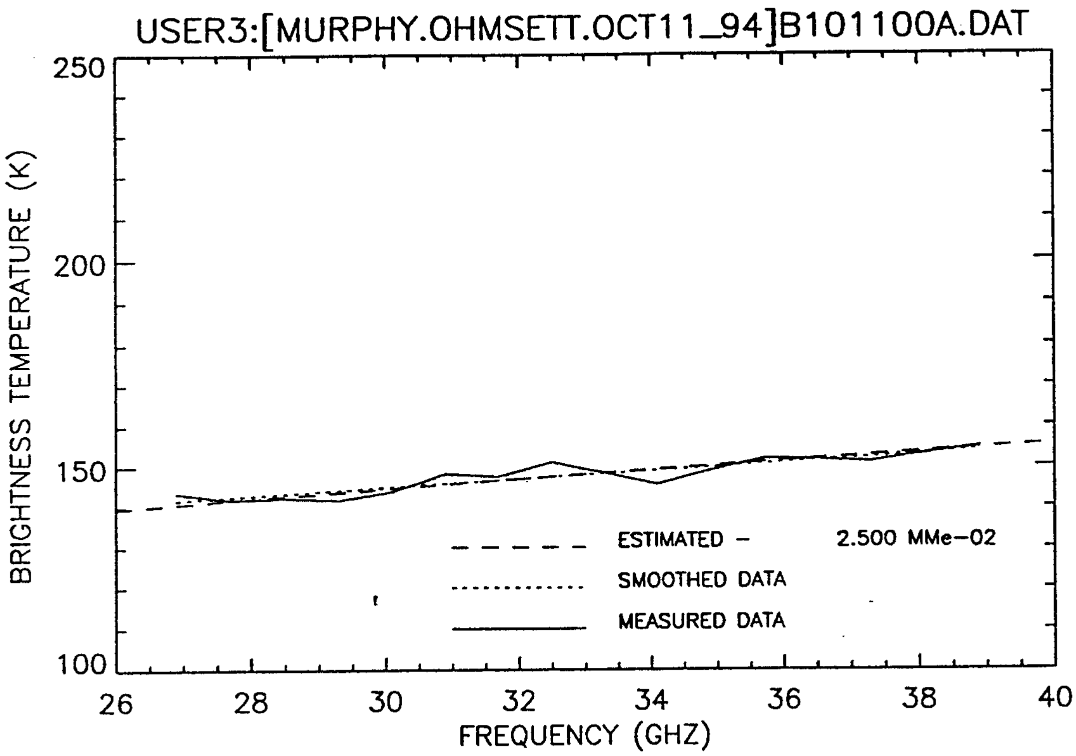

Figure C-1 T^B Versus Frequency Plot for Background Water, 11 October 1994, Pass 1

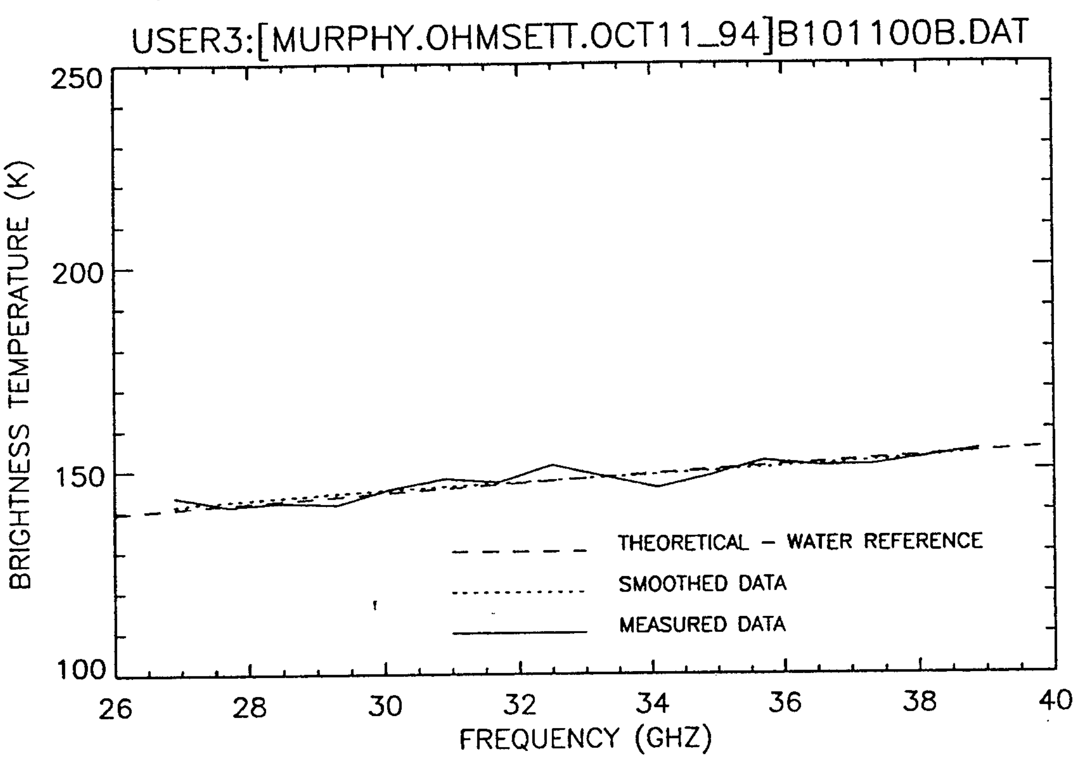

Figure C-2 T^B Versus Frequency Plot for Background Water, 11 October 1994, Pass 2

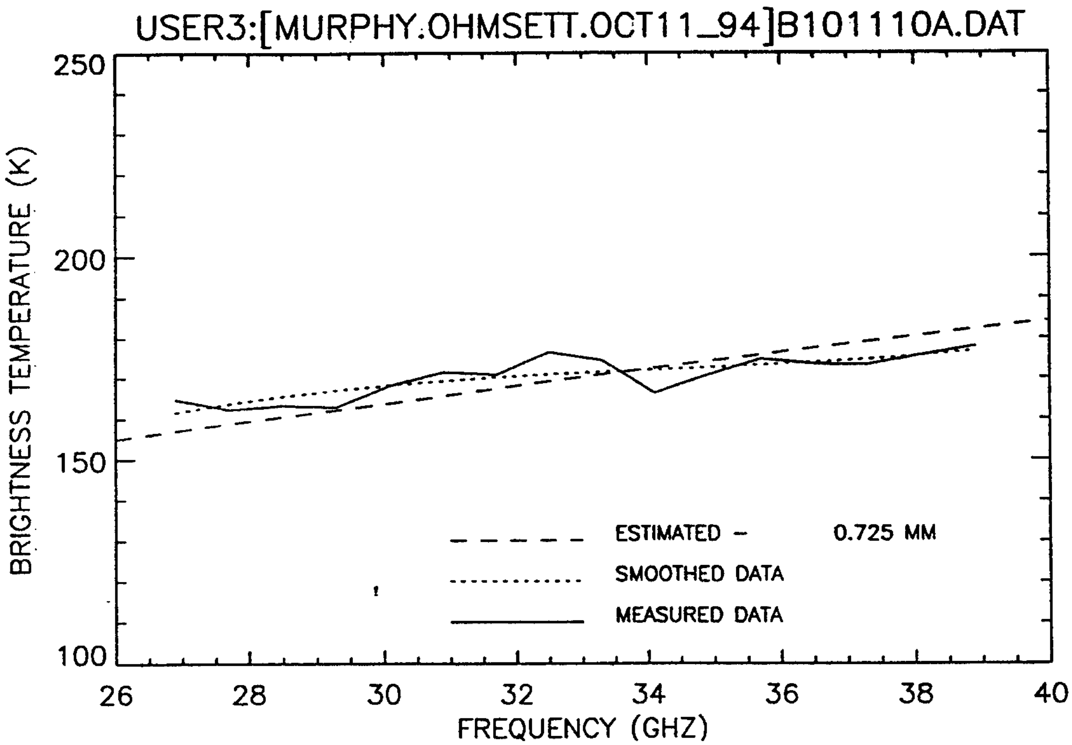

Figure C-3 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, RECCO 60, 11 October 1994, Pass 1

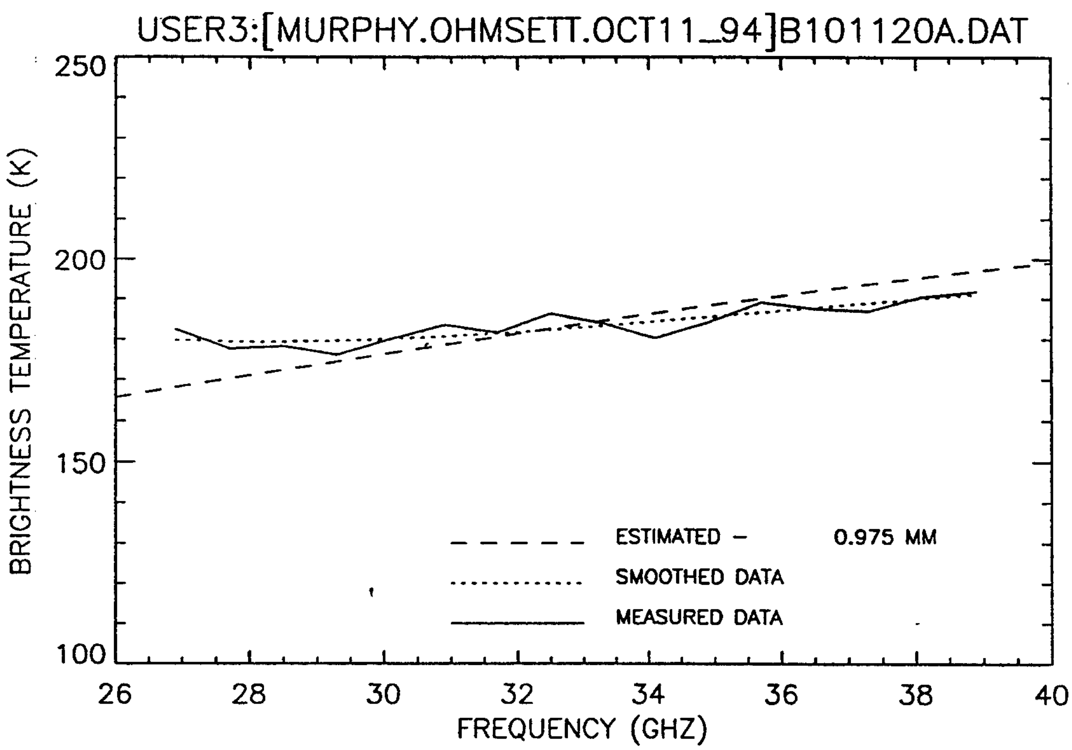

Figure C-4 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, RECCO 60, 11 October 1994, Pass 1

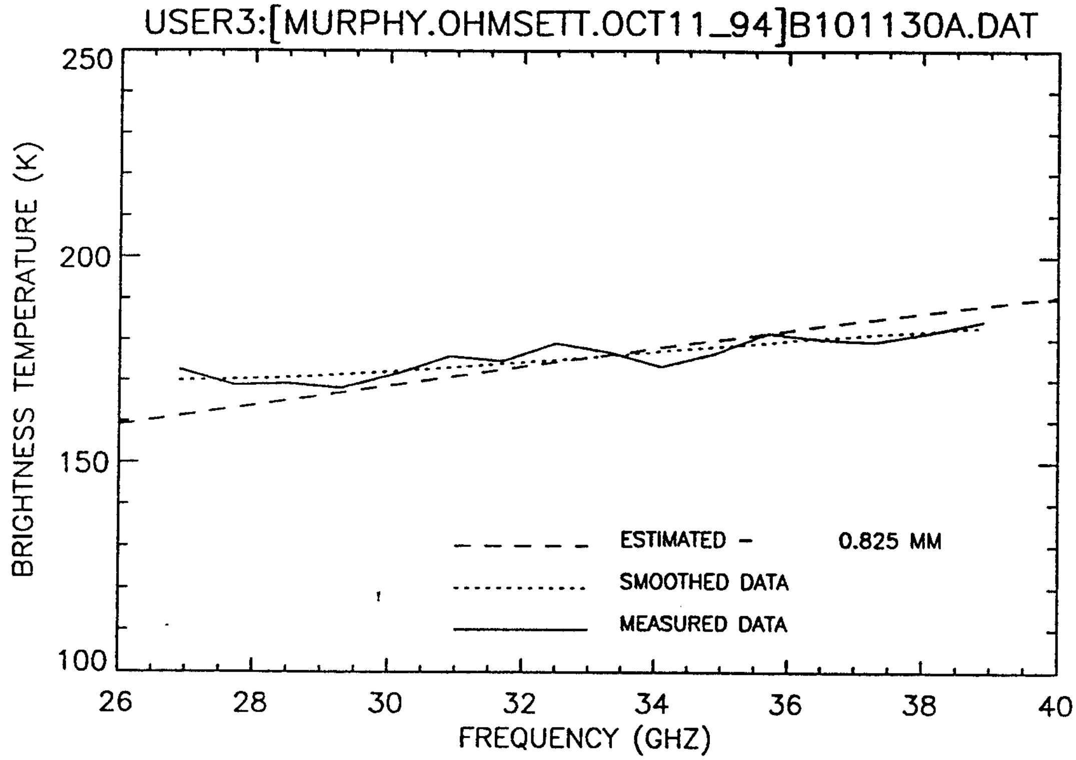

Figure C-5 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, RECCO 60, 11 October 1994, Pass 1

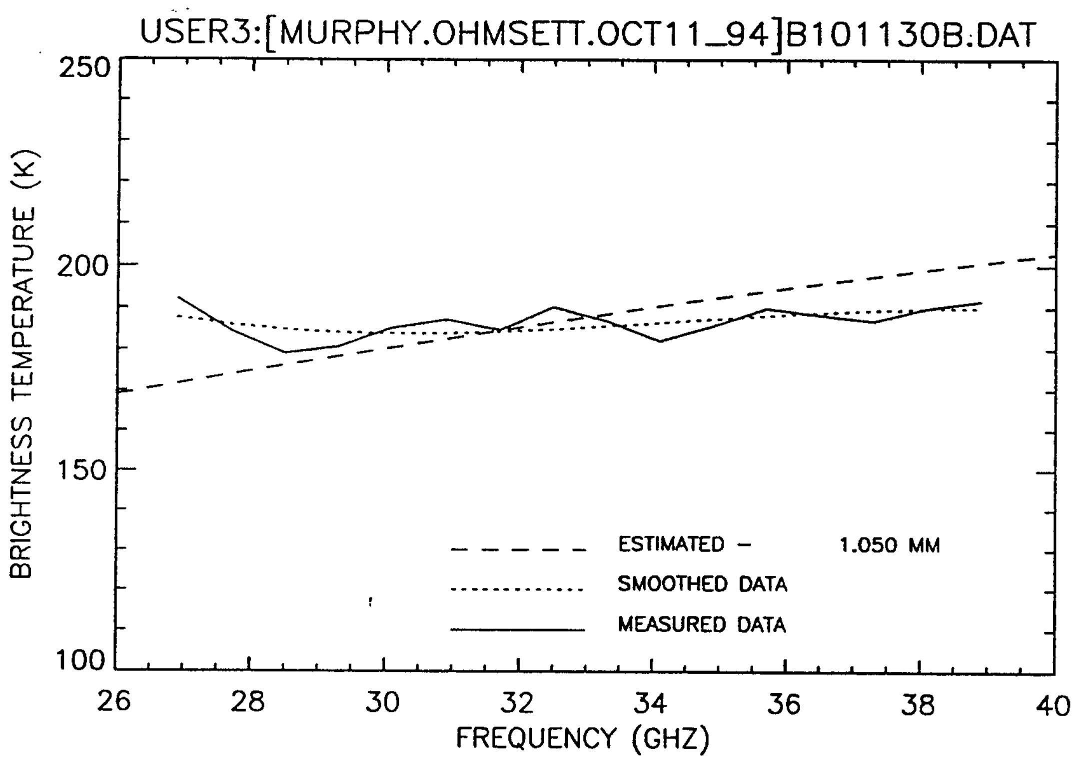

Figure C-6 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, RECCO 60, 11 October 1994, Pass 2

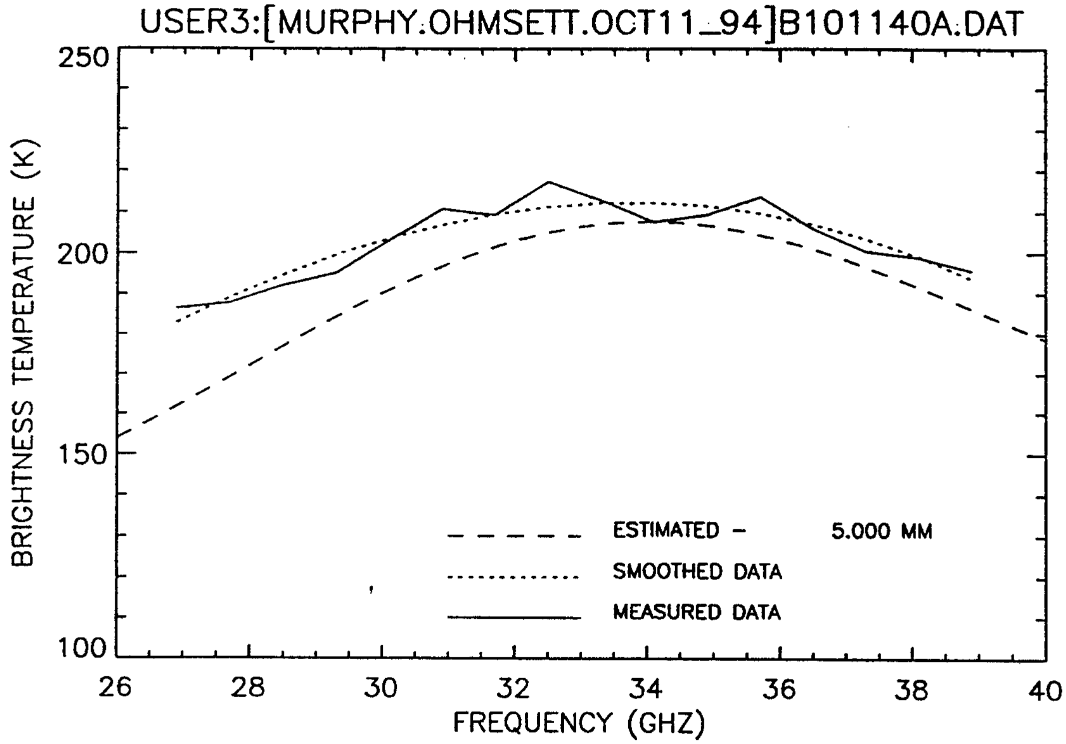

Figure C-7 T^B Versus Frequency Plot for 4.0 mm Uniform Oil Thickness, RECCO 60, 11 October 1994, Pass 1

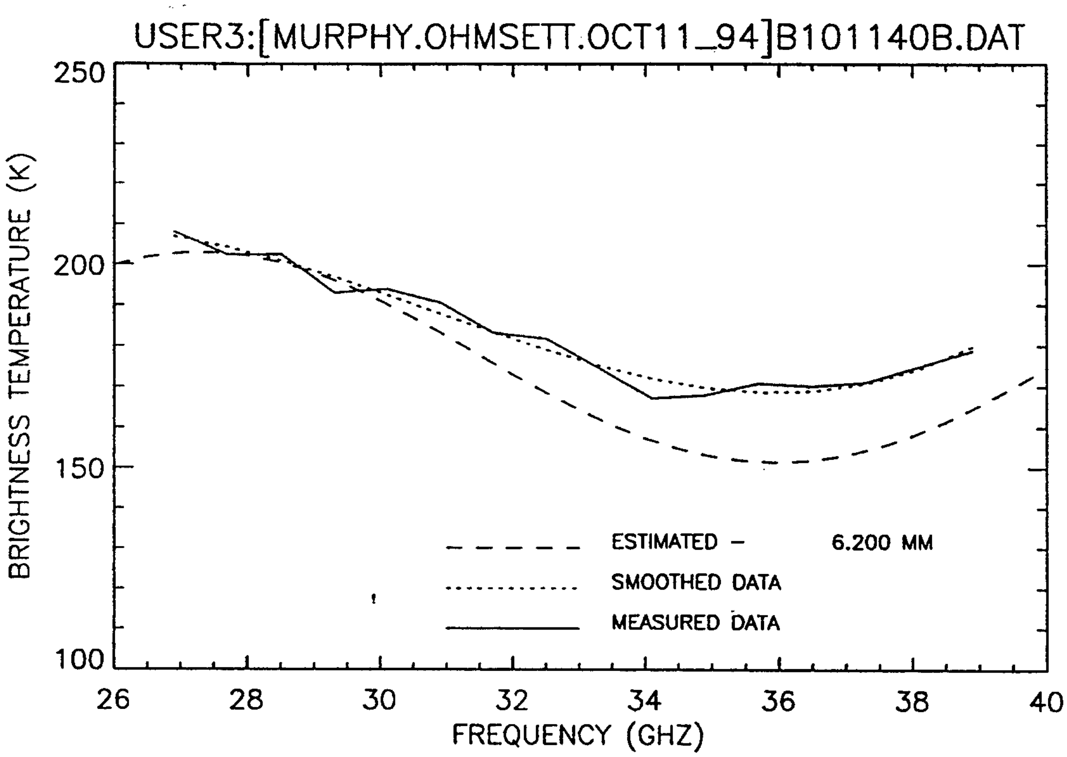

Figure C-8 T^B Versus Frequency Plot for 4.0 mm Uniform Oil Thickness, RECCO 60, 11 October 1994, Pass 2

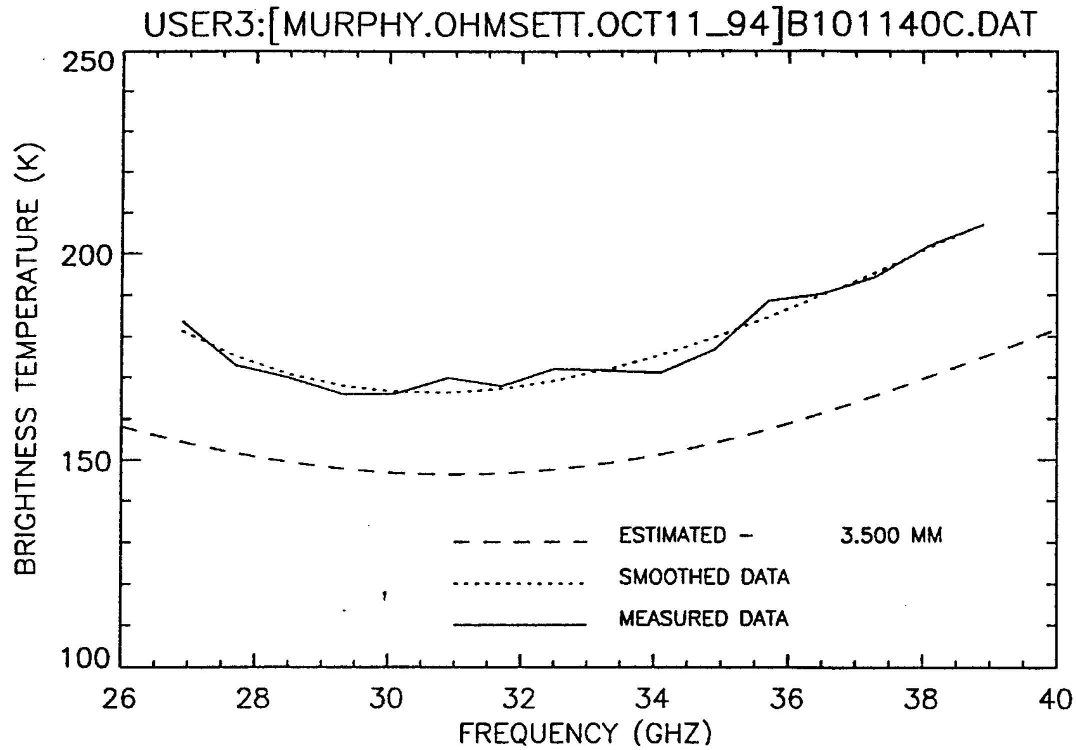

Figure C-9 T^B Versus Frequency Plot for 4.0 mm Uniform Oil Thickness, RECCO 60, 11 October 1994, Pass 3

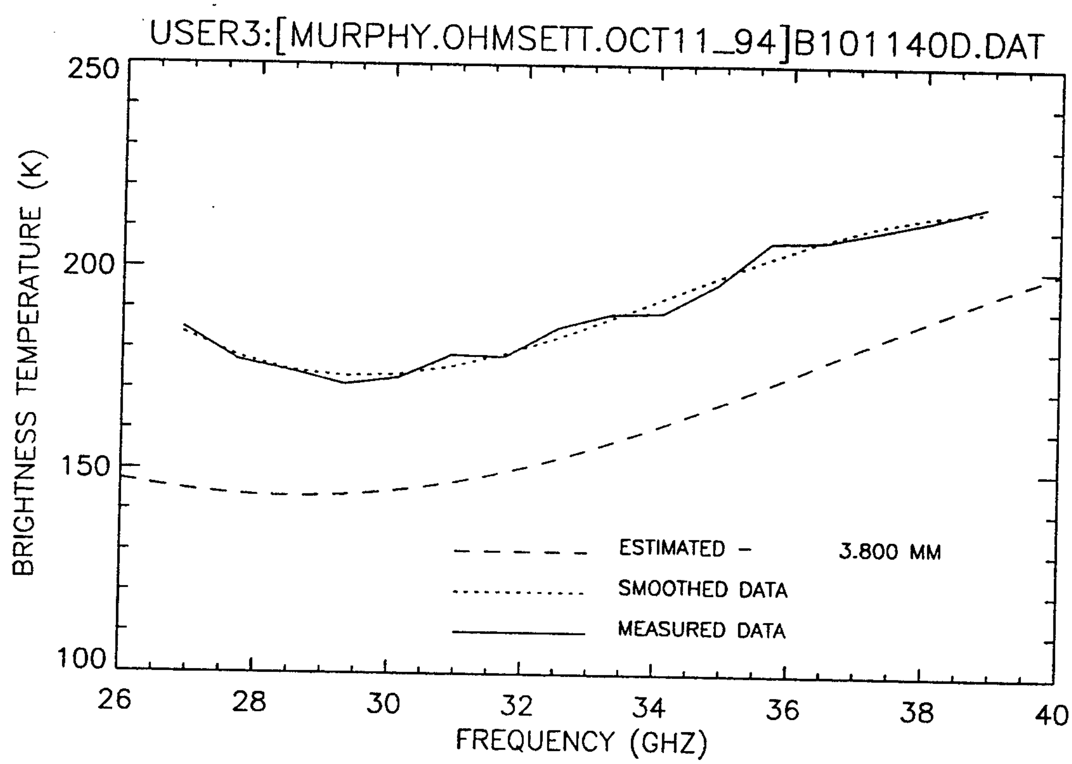

Figure C-10 T^B Versus Frequency Plot for 4.0 mm Uniform Oil Thickness, RECCO 60, 11 October 1994, Pass 4

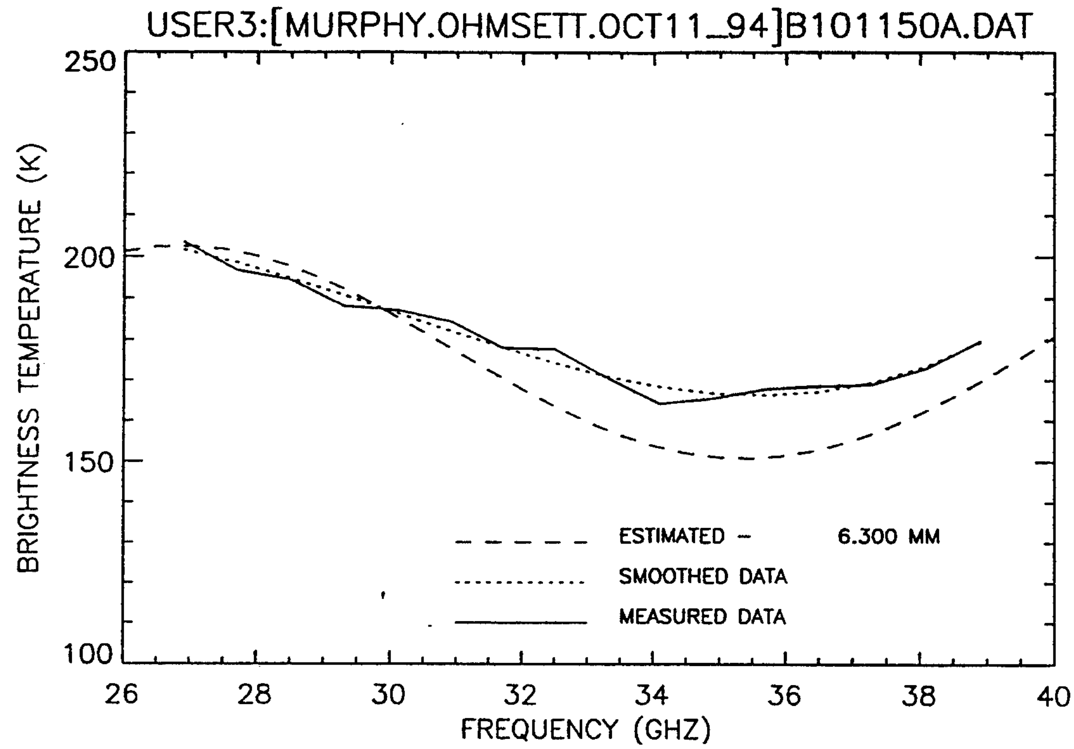

Figure C-11 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, RECCO 60, 11 October 1994, Pass 1

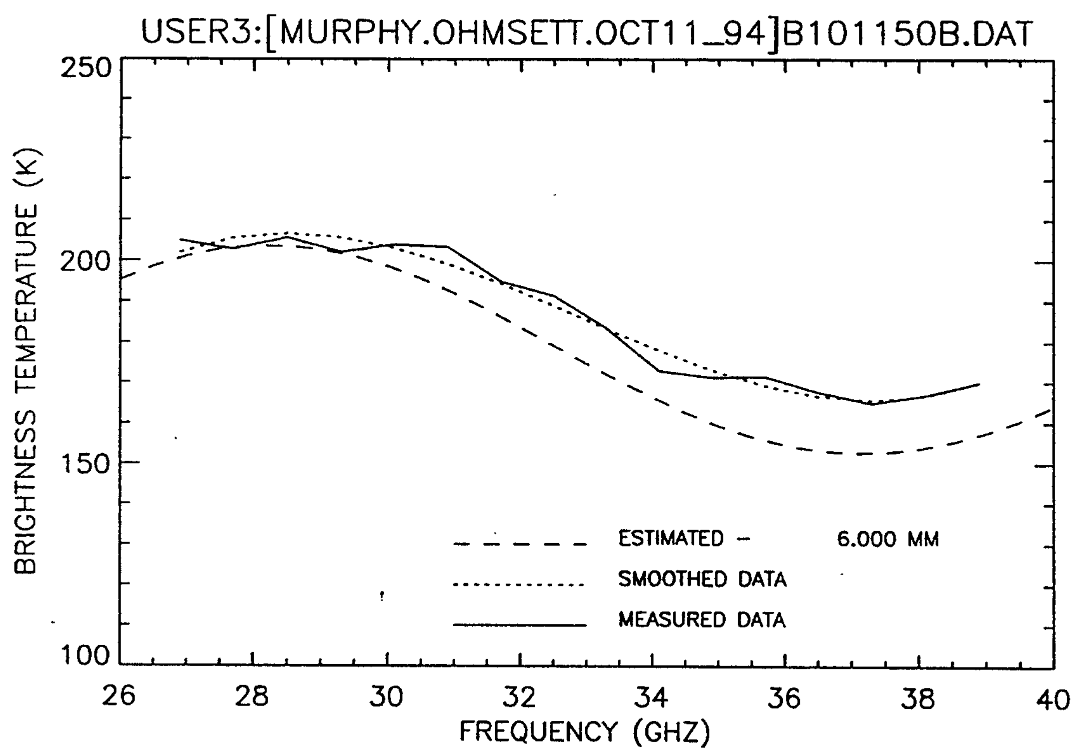

Figure C-12 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, RECCO 60, 11 October 1994, Pass 2

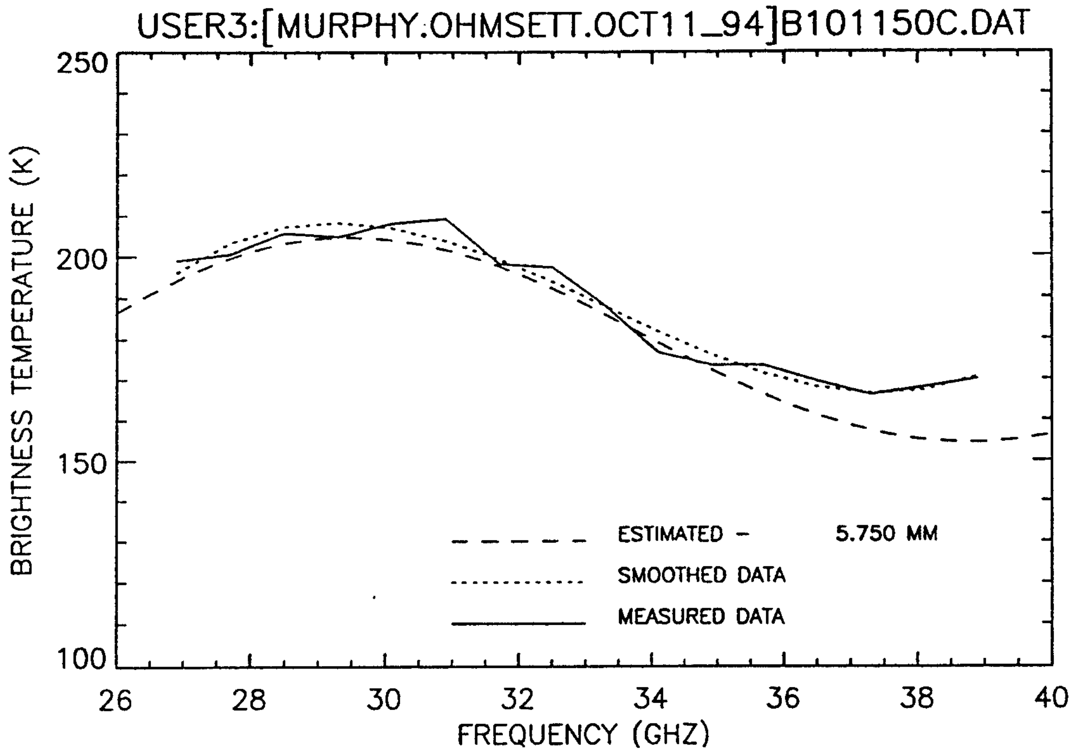

Figure C-13 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, RECCO 60, 11 October 1994, Pass 3

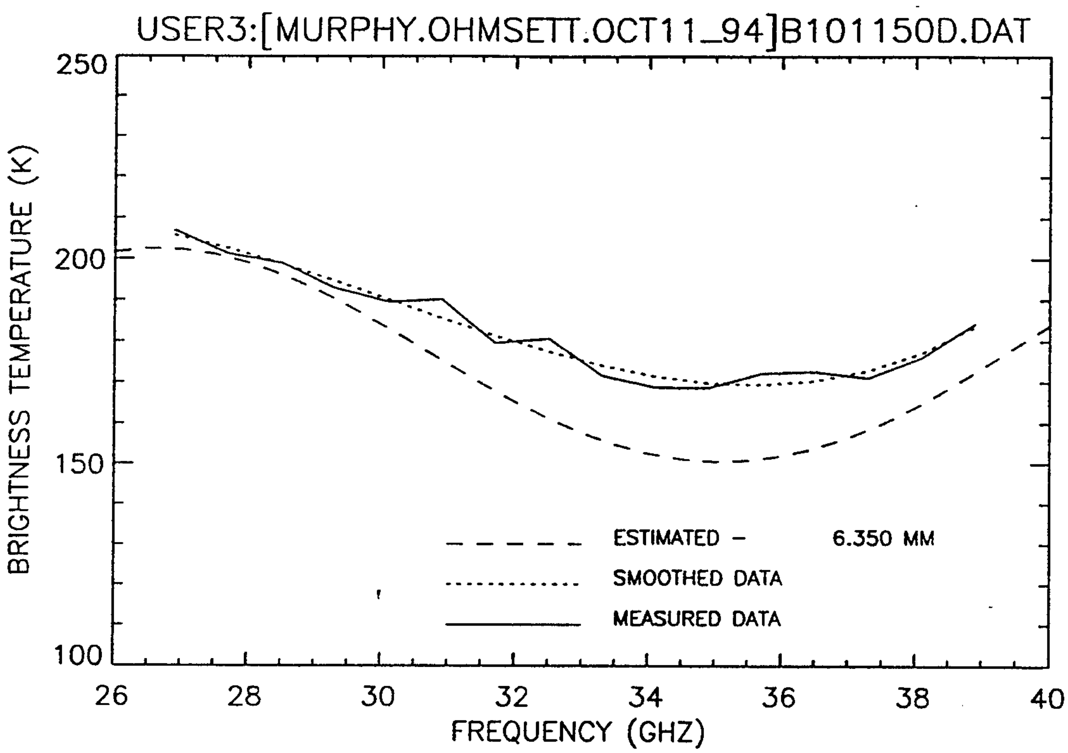

Figure C-14 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, RECCO 60, 11 October 1994, Pass 4

The following data set was collected on 12 October, using the RECCO 60 oil target deployed on 11 October after it had settled overnight. The 'C' measurements were collected over water with no oil film, followed by the 'D' measurements that were collected over the RECCO 60 oil target, and comprise a total of eleven measurement sets. Seventeen 'E' measurement sets were also collected on 12 October, using dyed diesel oil targets of different thicknesses.

C101200A - This is the water reference that was chosen for this set of measurements and resulting T^B plots. After reviewing the results of the following two measurements, it was determined that the FSR was still "drifting" due to warm-up effects. Subsequently, C101200C was used as the reference for analysis; the results are not plotted here, however, the algorithm results from these two comparisons are shown in Chapter 4.

C101200B - This curve is slightly warmer than the chosen water reference measurement, and is a good match to the estimation algorithm result of 0.150 mm. Since this was taken early in the morning, the drift might be associated with the electronics still 'warming-up'; the active heater and bipolar transistor amplifiers have not reached a steady state temperature.

C101200C - This curve is slightly warmer than the chosen water reference measurement, and is a good match to the estimation algorithm result of 0.075 mm. Since this was taken early in the morning, the drift may be associated with the electronics still 'warming-up'; the active heater and bipolar transistor amplifiers have not reached a steady state temperature. Section 4.2.2 compares the results obtained from this test session when the first water measurement (C101200A) is used as the reference, and when this measurement is used as the reference.

After the clear water measurements were complete, the bridge was moved to the center of the RECCO 60 oil target pool. The following two measurements were collected from the center of this pool.

D101250A - This curve is a poor match to the estimation algorithm result of 8.625 mm. This curve exhibits a peak in the center of the band that indicates a possible match to the 5.2 mm estimate shown on the plot. Overall this curve exhibits relatively low amplitude modulation.

D101250B - This curve is a poor match to the algorithm estimate of 0.675 mm. There is a characteristic peaking in center of band that indicates a possible match to thicknesses between 5.1 (shown) and 5.2 mm. Overall this curve exhibits relatively low amplitude modulation.

The bridge was moved so that the FSR could measure an area in the north end of the same oil target pool. Based on visual observation of the pool, this end seemed to have a thinner oil film than in the center of the pool.

D101250C - This curve is a fair match to the algorithm estimate of 0.0 mm. The measurement has an extremely low T^B across the entire band, although there is a slight curve shape similar to 3.6 mm. The result in this case is inconclusive.

D101250D - This curve is a fair match to the algorithm estimate of 3.85 mm, although the ends of the curve are showing inflections that are closer to a 4.0 - 4.4 mm characteristic as estimated by the correlation result.

D101250E - This curve is a poor match to the algorithm estimate of 0.75 mm. The curve exhibits a characteristic peaking in center of band indicating a possible match to the 5.0 - 5.2 mm curve shown on the plot.

The bridge was moved to the south side of the oil target pool. Based on visual observation, this part of the pool seemed thicker than the center.

D101250F - This curve is a poor match to the algorithm estimate of 2.8 mm. The curve has two inflection points and a negative slope through mid-band indicative of a 5.9 mm curve as shown on the plot. This matches well with the correlation result.

D101250G - This curve is a poor match to the algorithm estimate of 3.15 mm. Based on the steep tails of the curve, and the null near mid-band, the curve matches a 6.65 mm estimate (shown) nearly as well.

D101250H - This curve is a poor match to the algorithm estimate of 3.225 mm. Based on the steep tails of the curve, and the null near mid-band, the curve matches a 6.7 mm estimate (shown) nearly as well.

An effort was made to check for the apparent oil target slope across the pool, however the OHMSETT bridge position data did not provide sufficient information to do so.

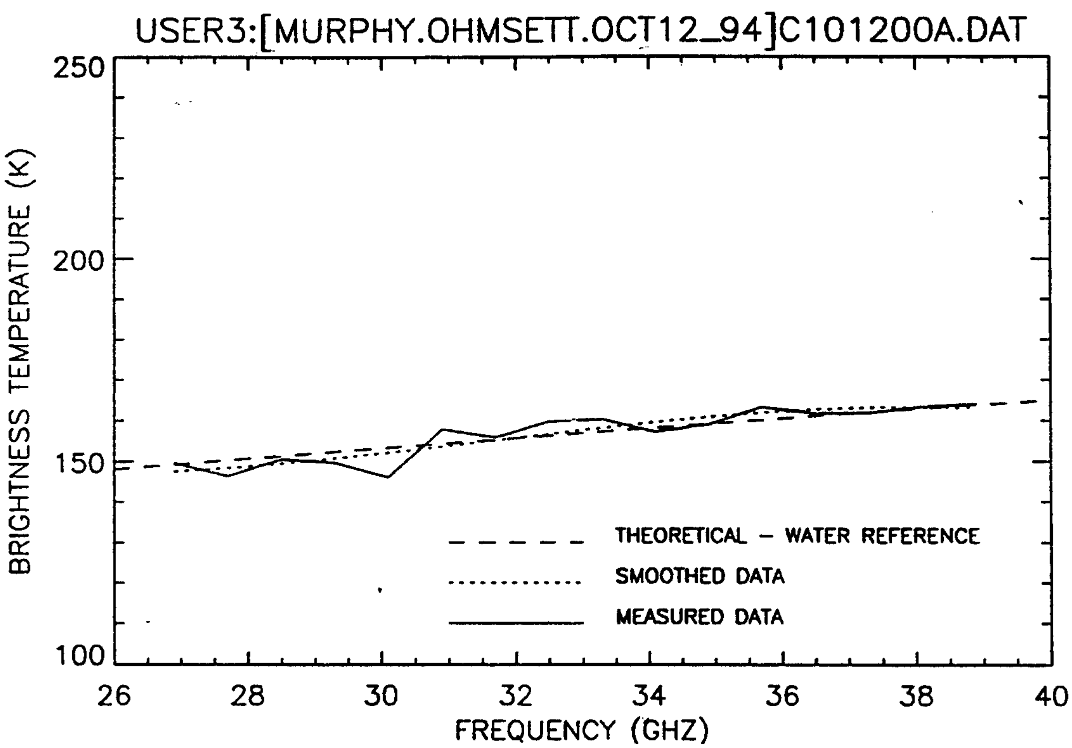

Figure C-15 T^B Versus Frequency Plot for Background Water, 12 October 1994, Pass 1

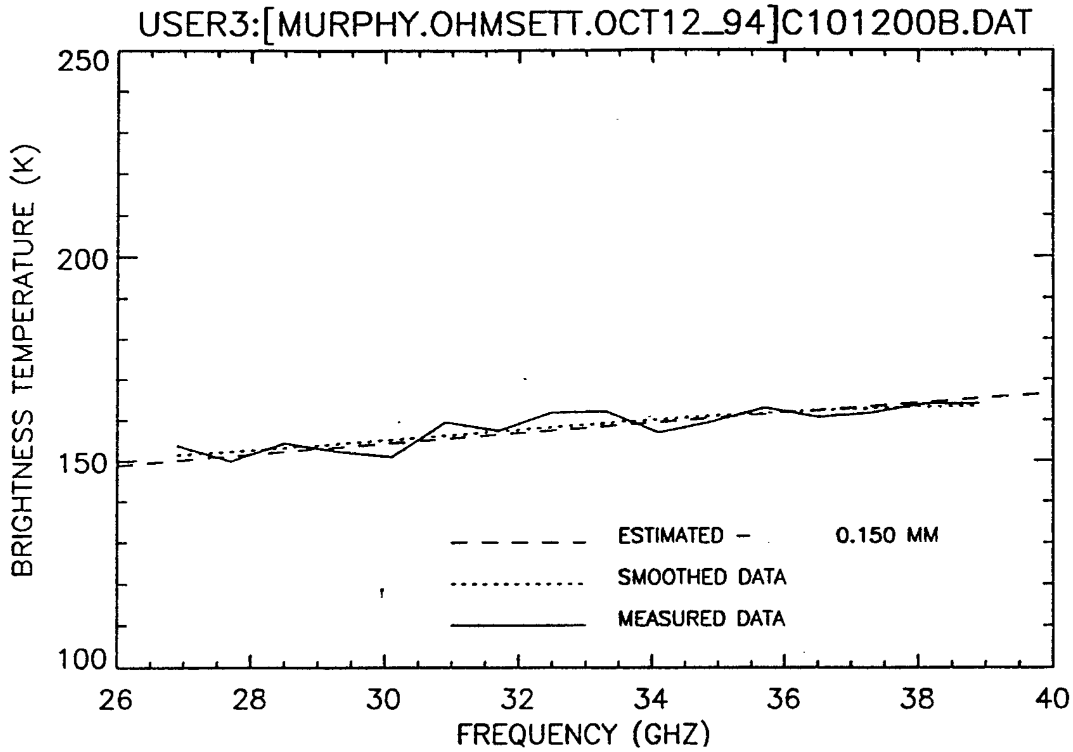

Figure C-16 T^B Versus Frequency Plot for Background Water, 12 October 1994, Pass 2

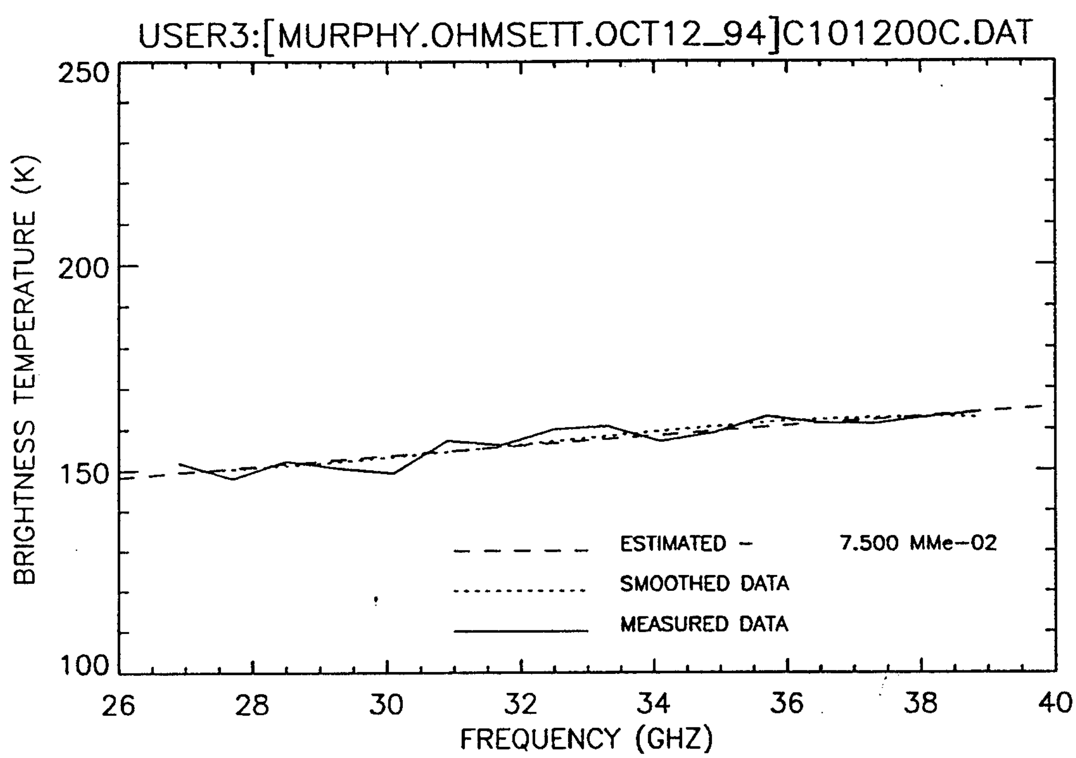

Figure C-17 T^B Versus Frequency Plot for Background Water, 12 October 1994, Pass 3

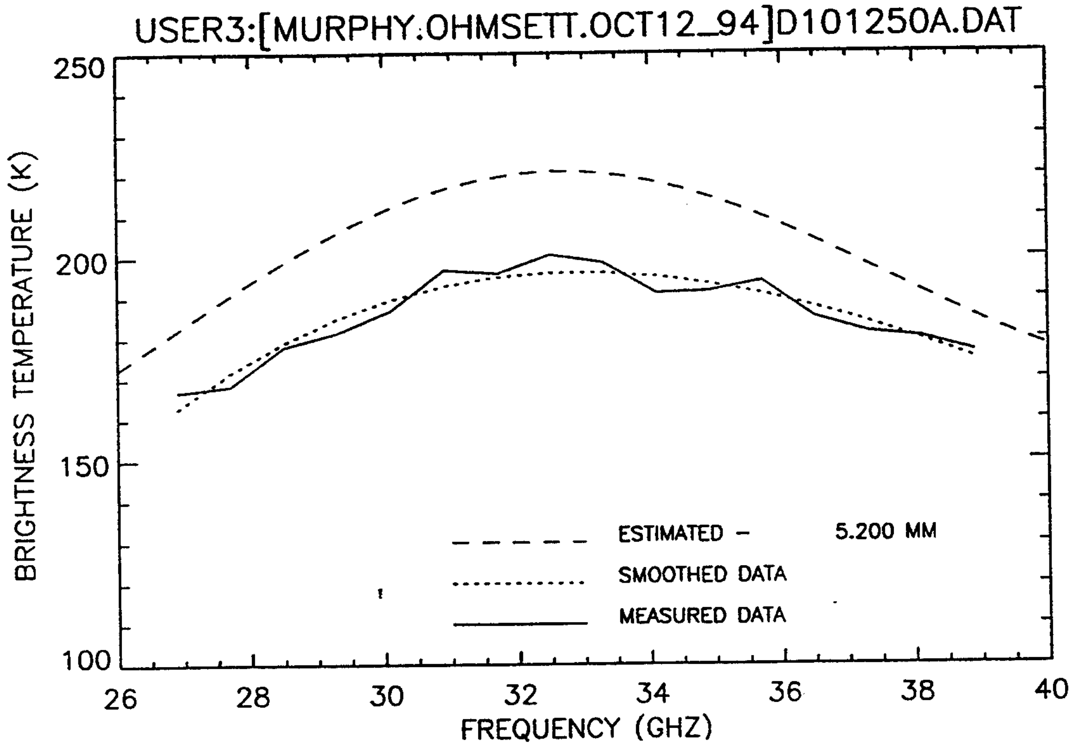

Figure C-18 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, RECCO 60, 12 October 1994, Pass 1

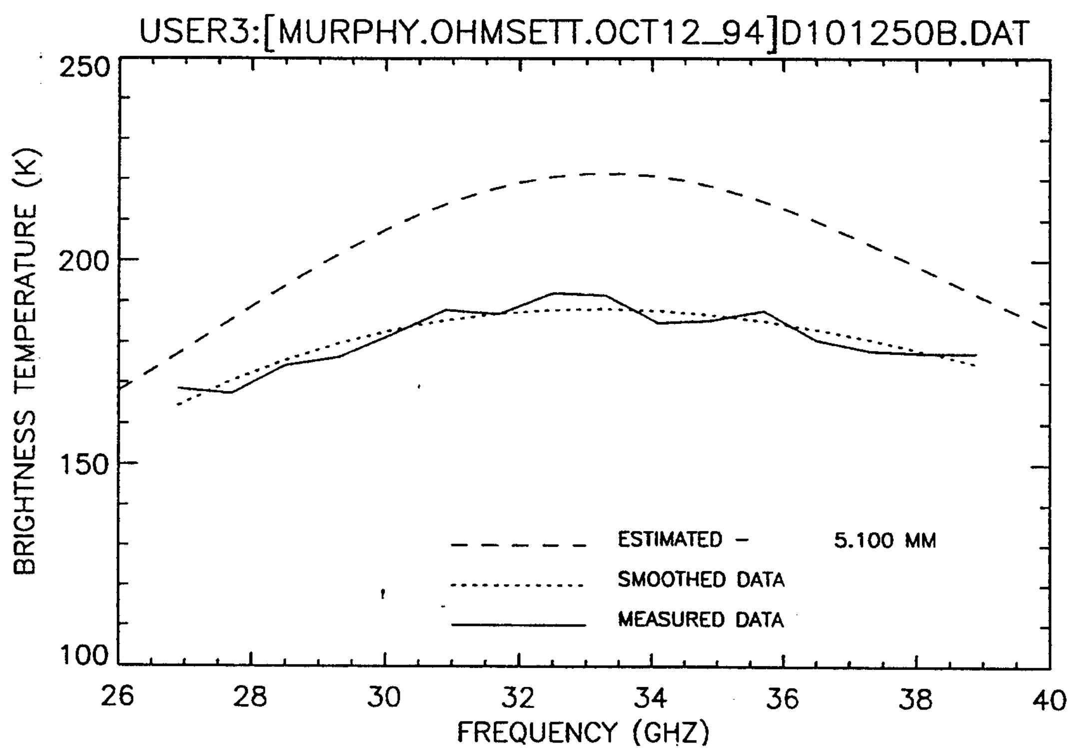

Figure C-19 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, RECCO 60, 12 October 1994, Pass 2

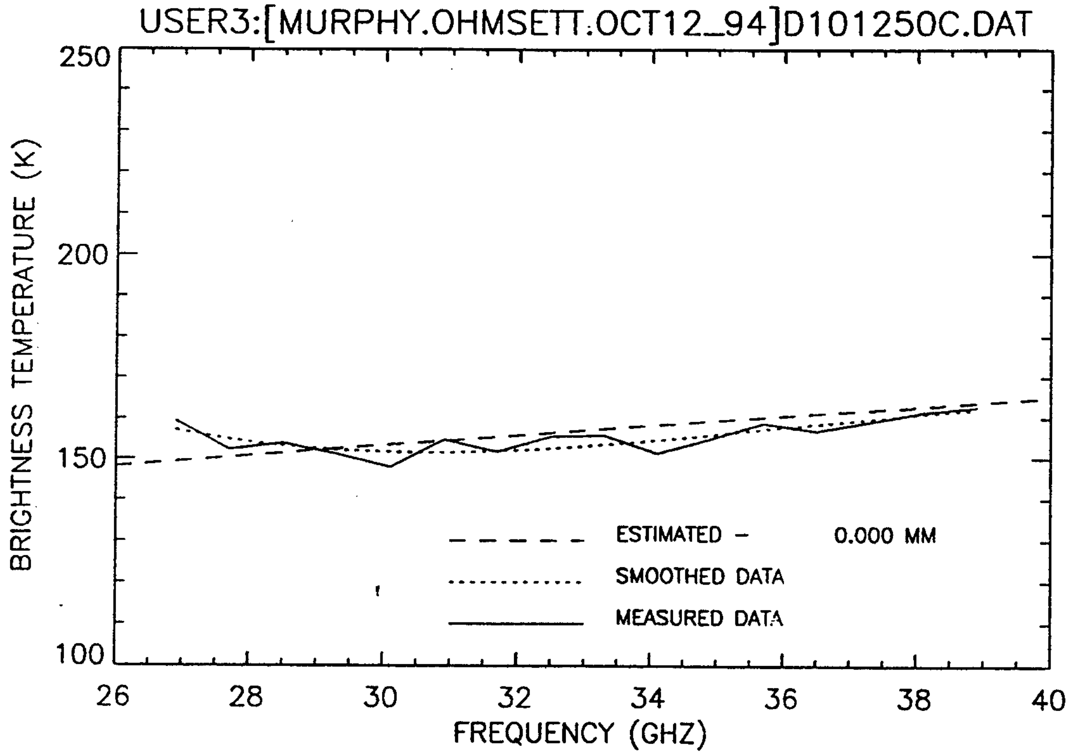

Figure C-20 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, RECCO 60, 12 October 1994, Pass 3

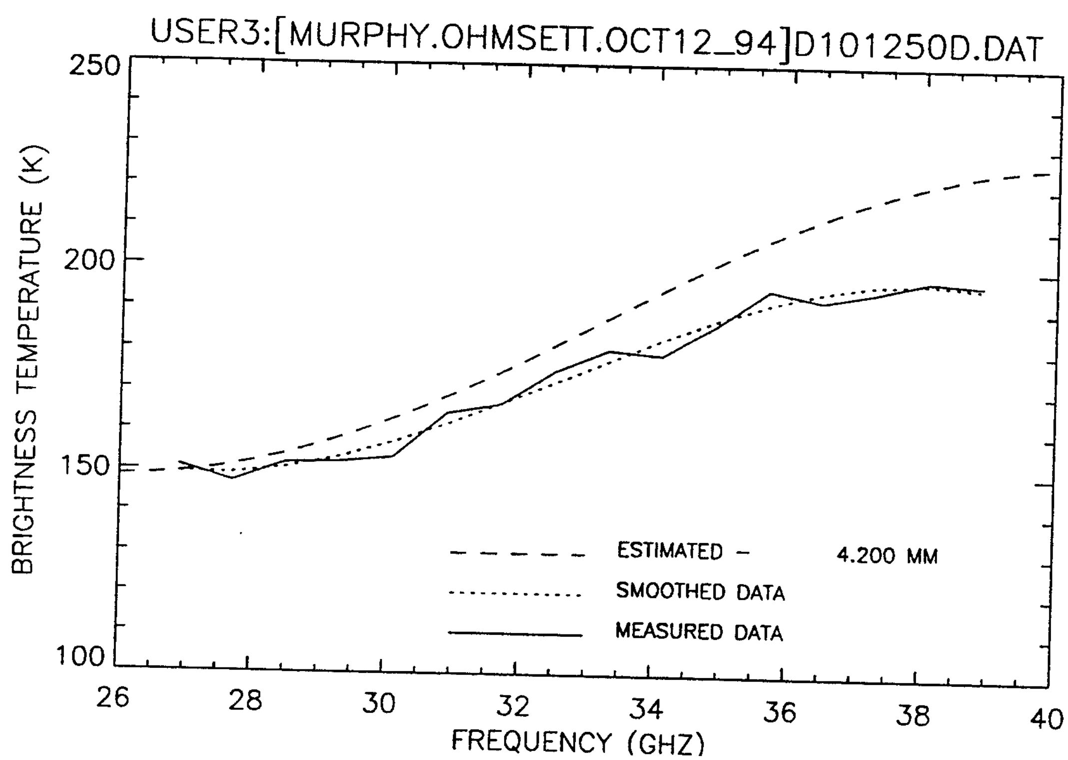

Figure C-21 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, RECCO 60, 12 October 1994, Pass 4

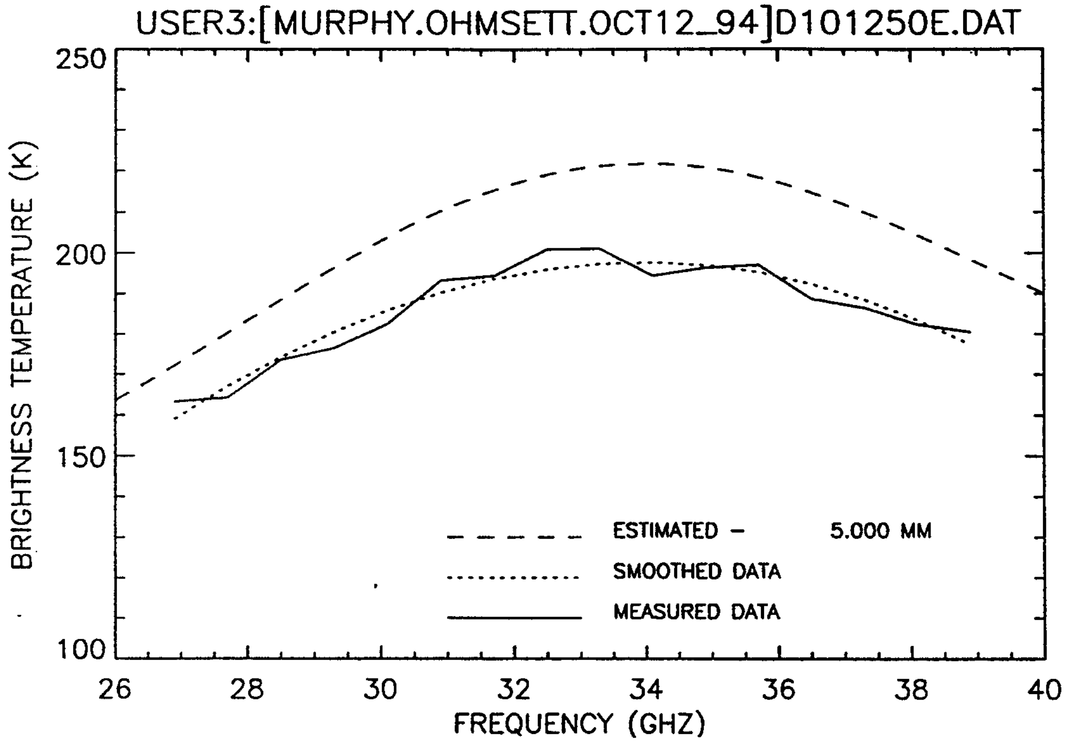

Figure C-22 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, RECCO 60, 12 October 1994, Pass 5

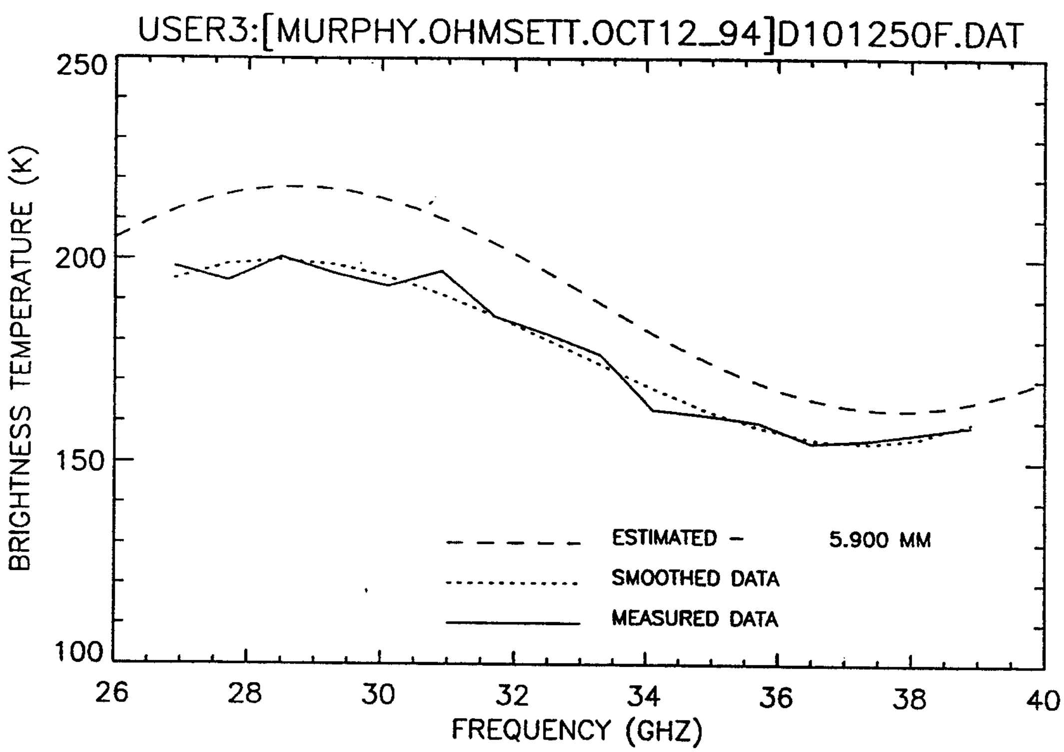

Figure C-23 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, RECCO 60, 12 October 1994, Pass 6

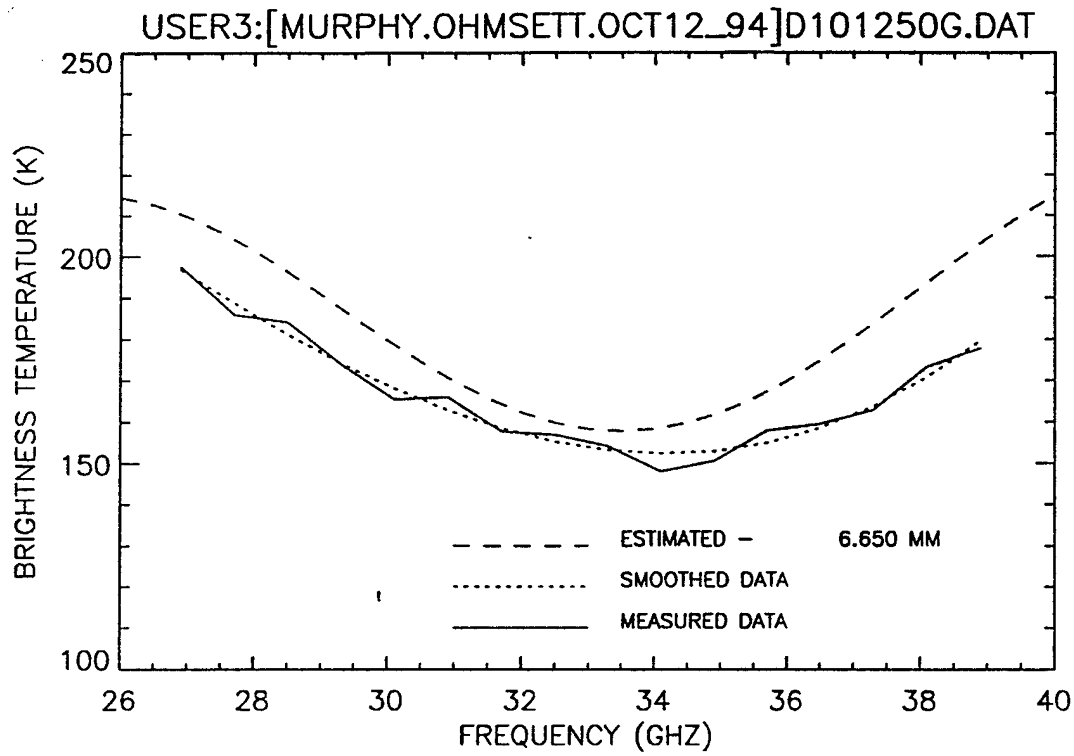

Figure C-24 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, RECCO 60, 12 October 1994, Pass 7

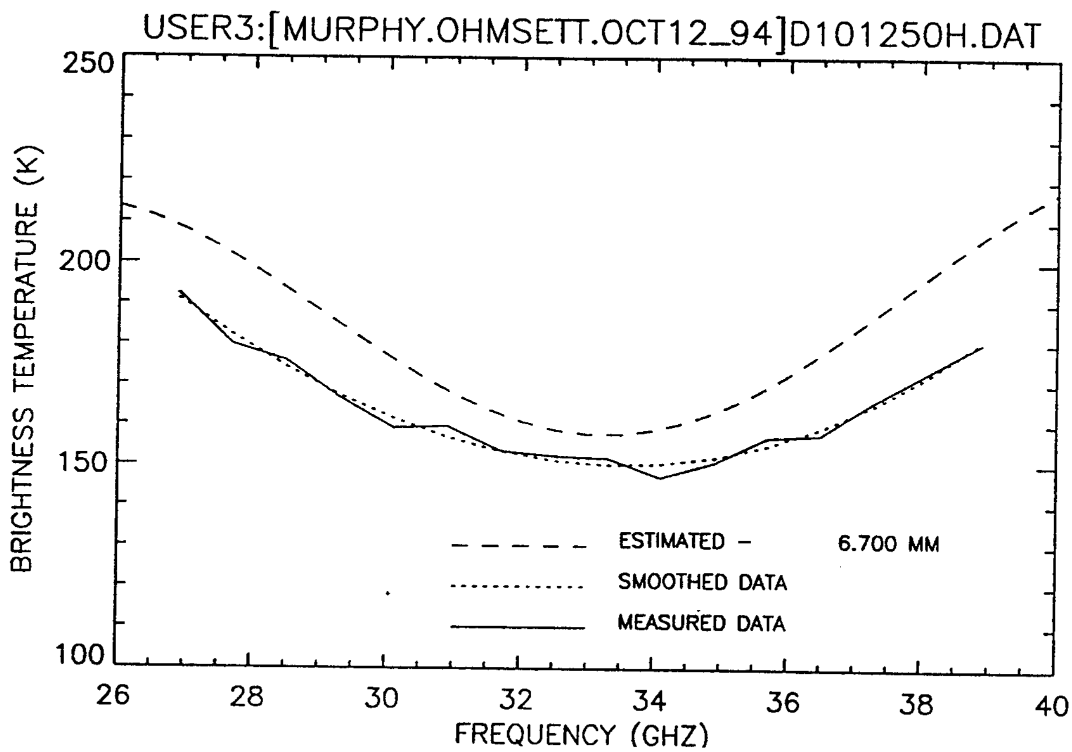

Figure C-25 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, RECCO 60, 12 October 1994, Pass 8

During the dry run the program managers decided that dyed diesel oil would be used in place of the RECCO 60 oil. A red dye was added to the diesel oil to provide a visual reference of where the oil was located within the target pools. The following measurements provide a baseline data set for diesel oil on water.

E101200A - This measurement was chosen to be the baseline water reference for the following measurements.

E101200B - This curve is a good match to the algorithm estimate of 0.0 mm.

E101210A -This curve is a fair match to the algorithm estimate of 0.9 mm. The curve is somewhat flatter (less slope) than expected for a 1.0 mm thickness. Based on the shape of the curve it could look like a 1.7 mm thickness but the mean T^B is much lower than would be expected.

E101210B - This curve is a fair match to the algorithm estimate of 0.95 mm. The curve is somewhat flatter (less slope) than expected for a 1.0 mm thickness. Based on the shape (flatness) of the curve it could look like a 1.7 mm thickness but the mean T^B is much lower than would be expected.

E101210C - This curve is a poor match to the algorithm estimate of 2.575 mm. The curve is much flatter (less slope) than expected for a 1.0 mm thickness and doesn't match the 1.7 mm well. The result is inconclusive.

E101220A - This appears to be a duplicate data set that matches E101210C, therefore, it is not plotted.

E101220B - This curve is a poor match to the algorithm estimate of 2.75 mm. The curve is much flatter (less slope) and has an overall lower T^B than expected for a 2.0 mm thickness. Based on the flat slope it could match a 1.9 mm estimate well but the overall T^B is much too low. The result is inconclusive.

E101230A - This curve is a good match to the algorithm estimate of 3.3 mm.

E101230B - This curve is a poor match to the algorithm estimate of 2.75 mm. The curve is much flatter (less shape characteristic) than expected for thicknesses near 3.0 mm. The result is inconclusive.

E101230C - This curve is a fair match to the algorithm estimate of 3.225 mm. This curve exhibits very little shape characteristic. No better estimate can be obtained visually.

E101240A - This curve is an excellent match to the algorithm estimate of 3.800 mm.

E101240B - This curve is an excellent match to the algorithm estimate of 3.850 mm.

E101240C - This curve is an excellent match to the algorithm estimate of 3.950 mm.

E101250A - This curve is a good match to the algorithm estimate of 4.600 mm.

E101250B - This curve is a good match to the algorithm estimate of 5.025 mm.

E101250C - This curve is a poor match to the algorithm estimate of 8.175 mm. The peak matches a 5.00 mm characteristic (shown), but the tails do not drop off as quickly. Either curve seems as good an estimate.

E101280A - This curve is a fair match to the algorithm estimate of 8.175 mm

E101280B - This curve is a good match to the algorithm estimate of 7.875 mm.

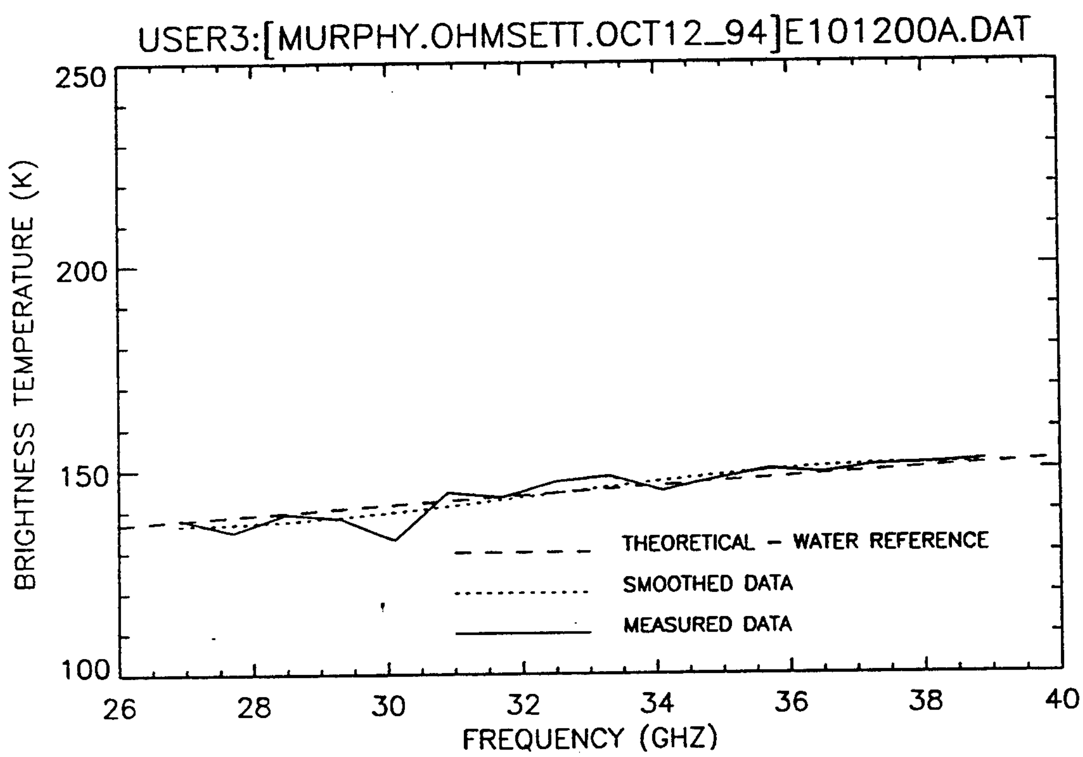

Figure C-26 T^B Versus Frequency Plot for Background Water at Diesel Oil Pool, 12 October 1994, Pass 1

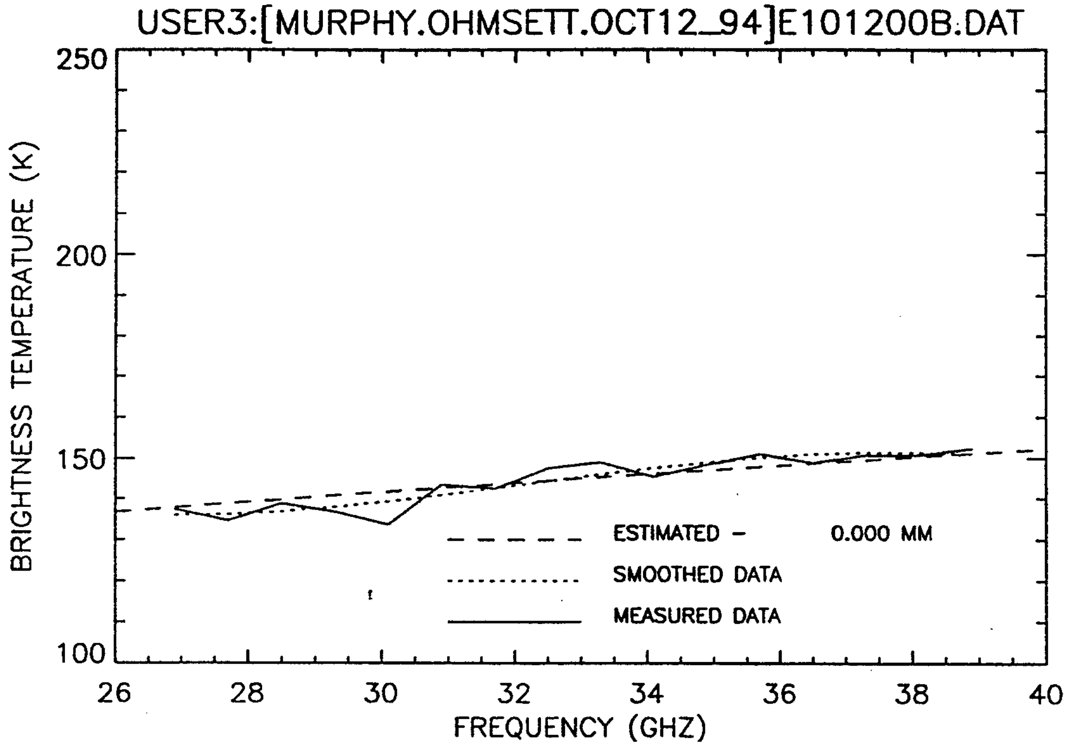

Figure C-27 T^B Versus Frequency Plot for Background Water at Diesel Oil Pool, 12 October 1994, Pass 2

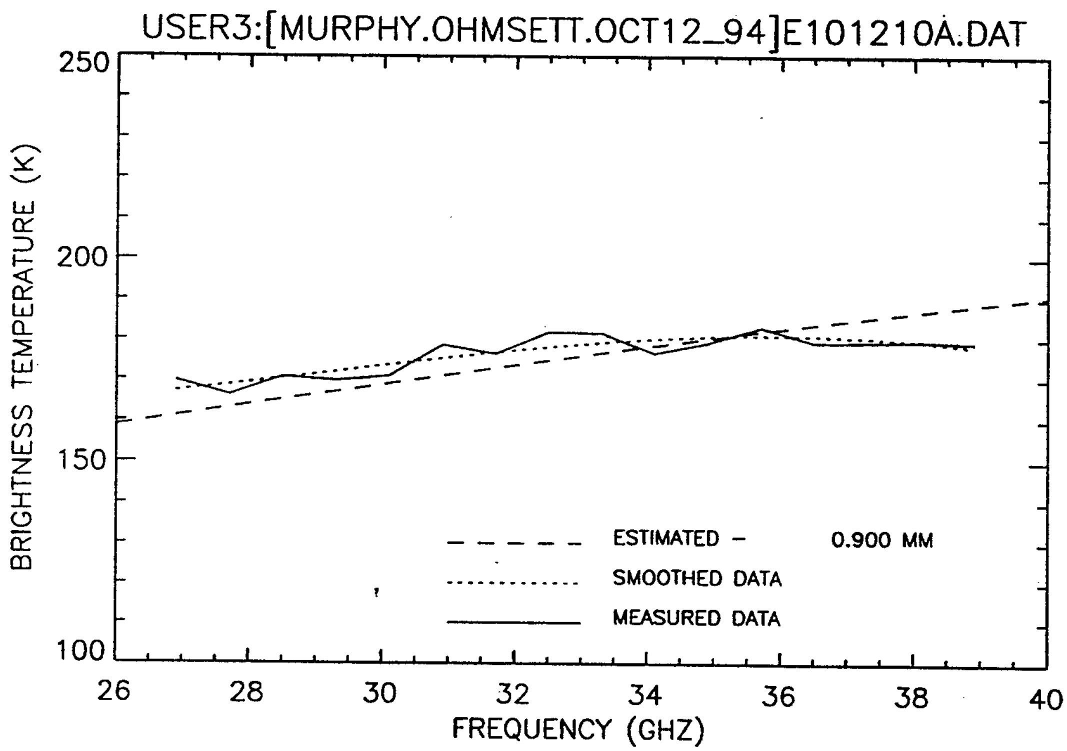

Figure C-28 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 1

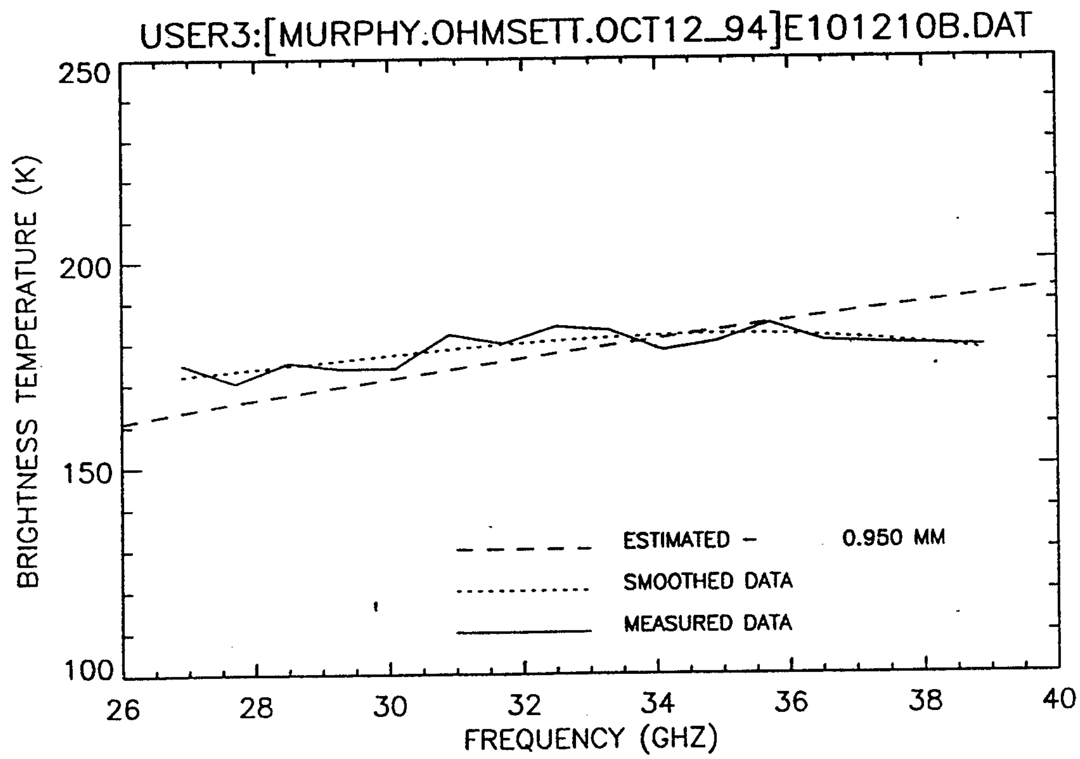

Figure C-29 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 2

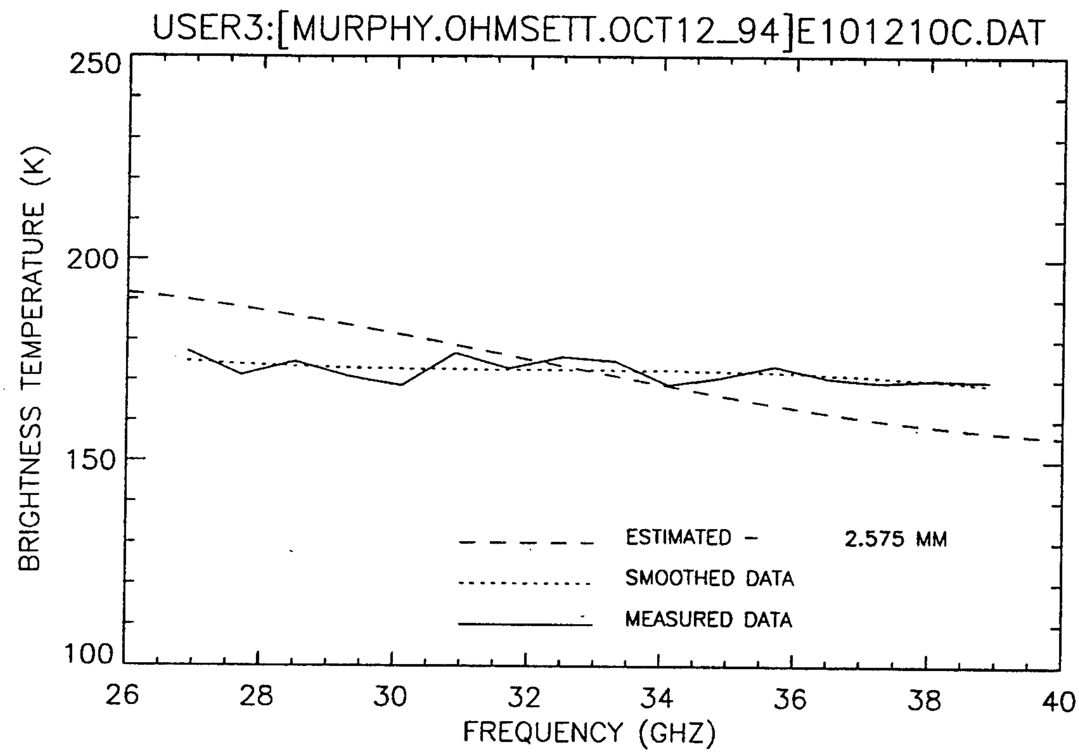

Figure C-30 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 3

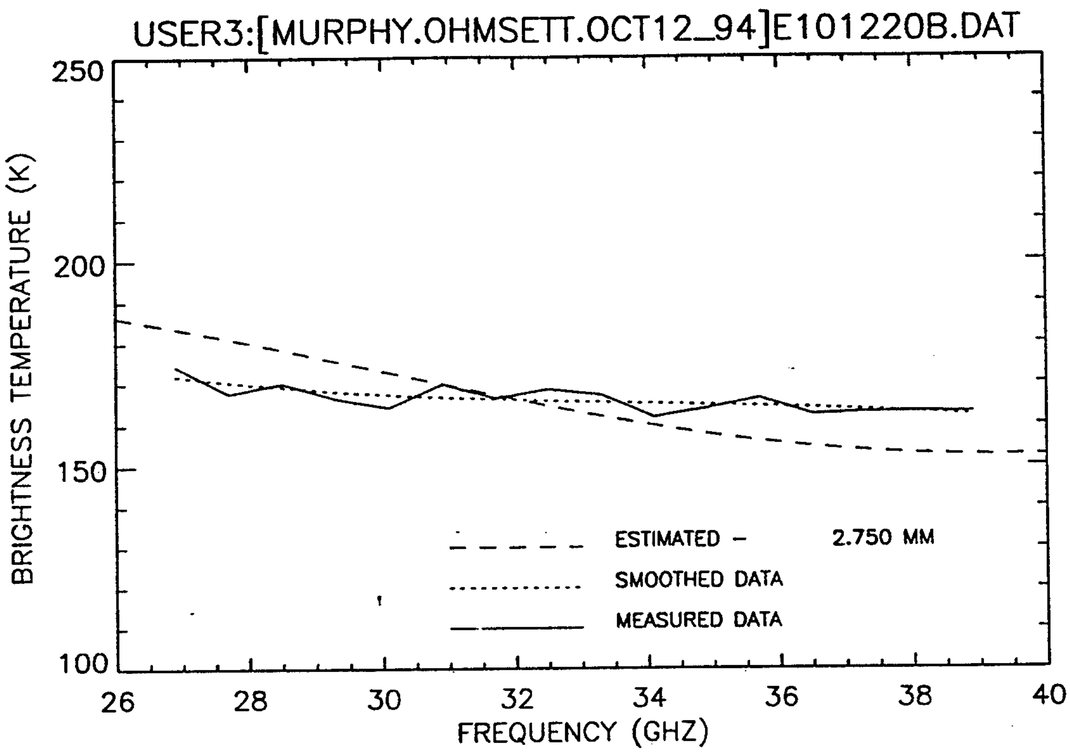

Figure C-31 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 2

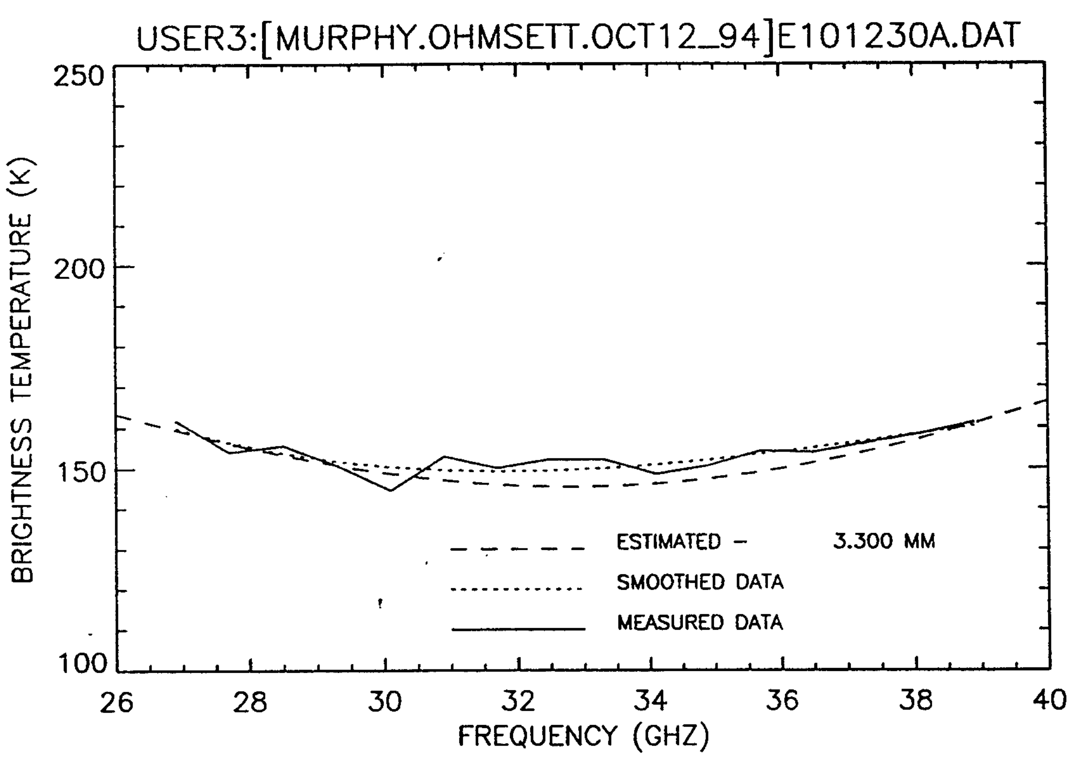

Figure C-32 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 1

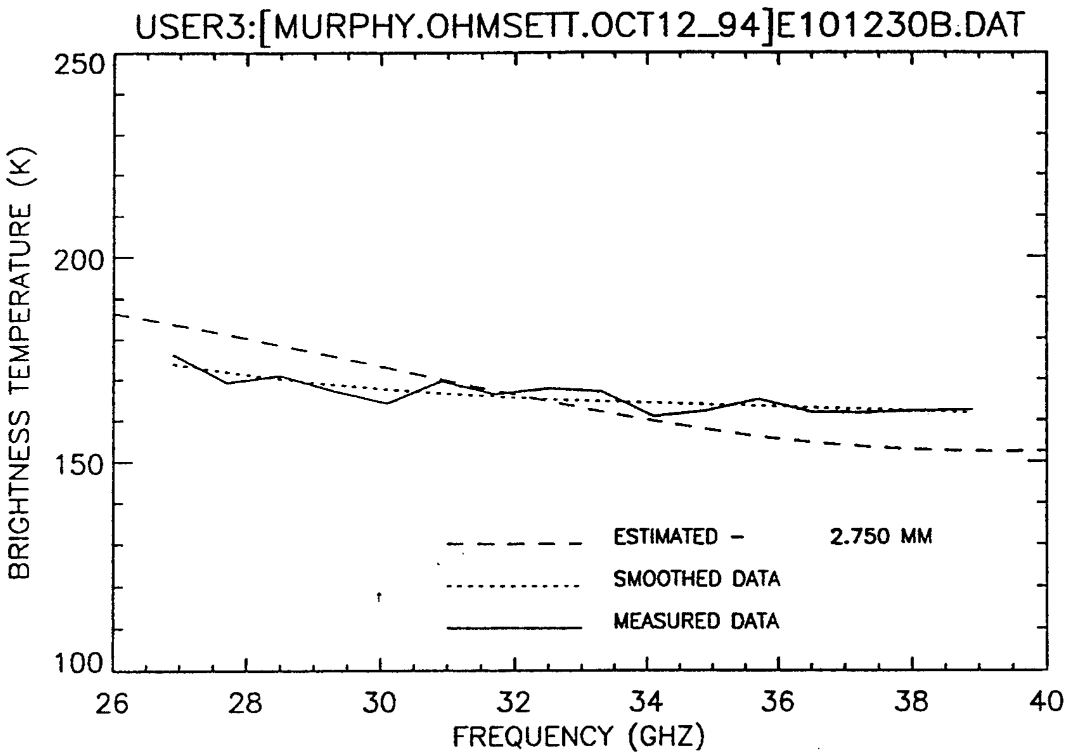

Figure C-33 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 2

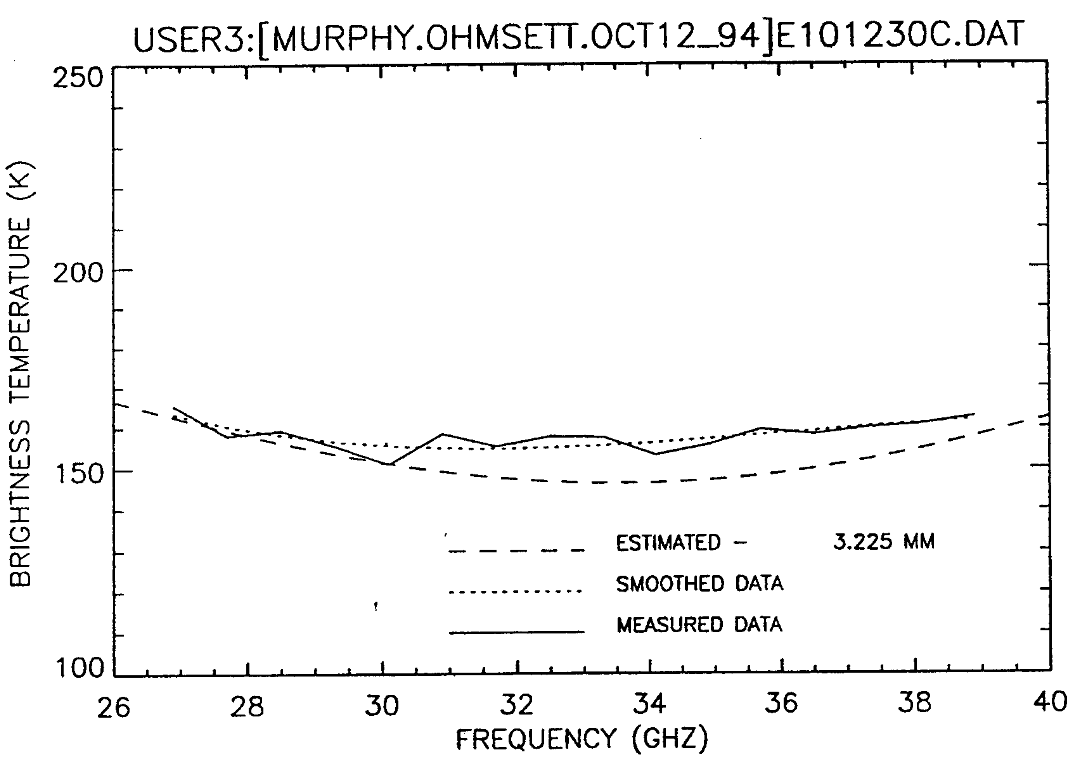

Figure C-34 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 3

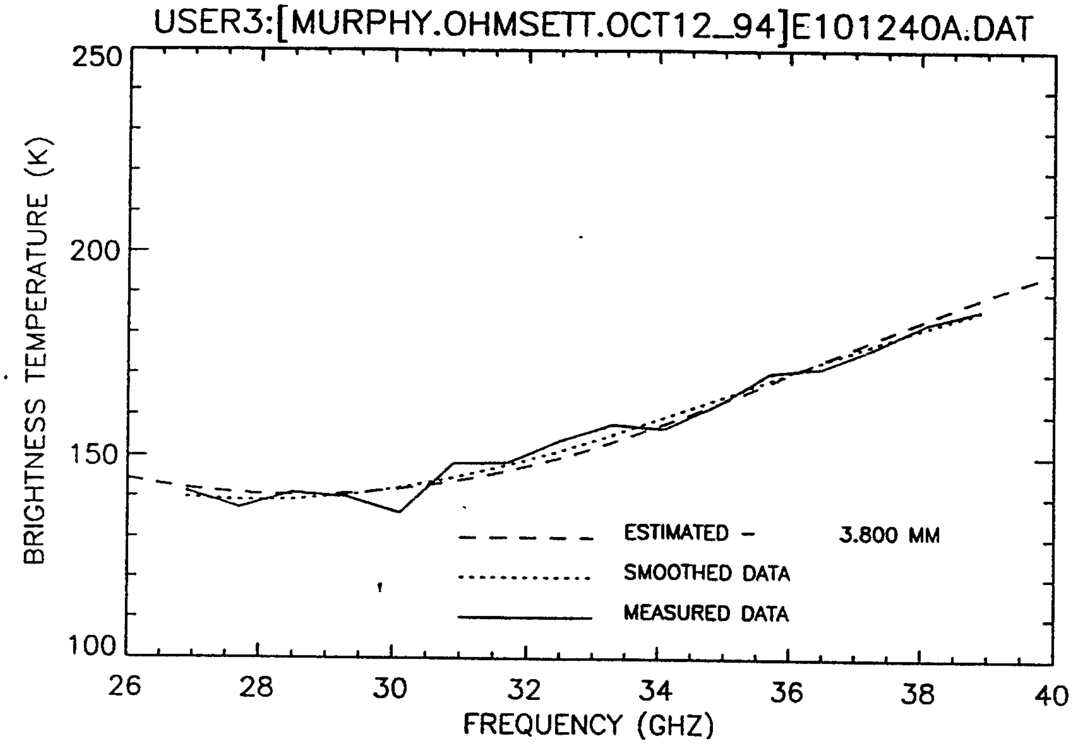

Figure C-35 T^B Versus Frequency Plot for 4.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 1

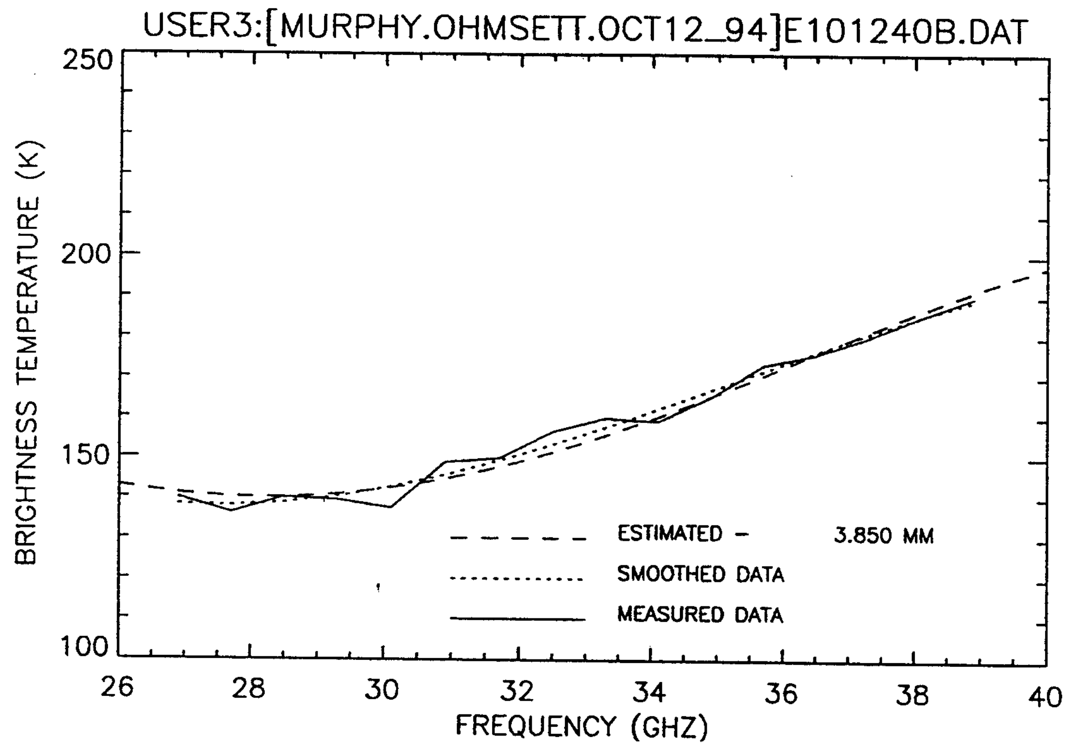

Figure C-36 T^B Versus Frequency Plot for 4.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 2

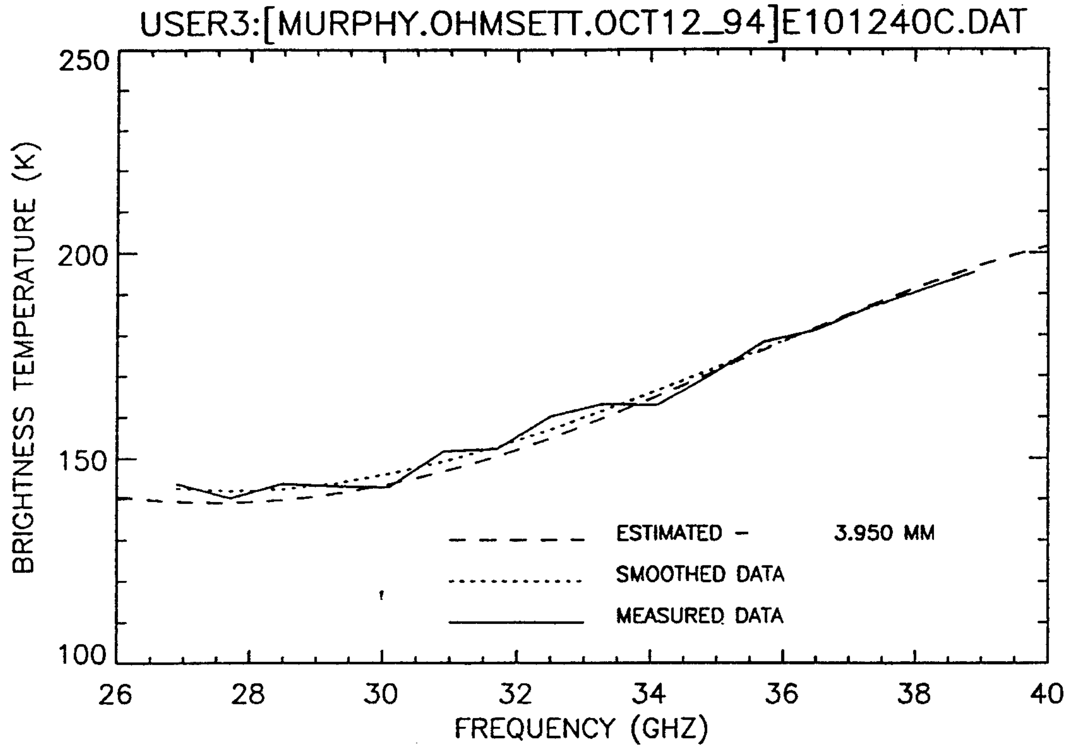

Figure C-37 T^B Versus Frequency Plot for 4.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 3

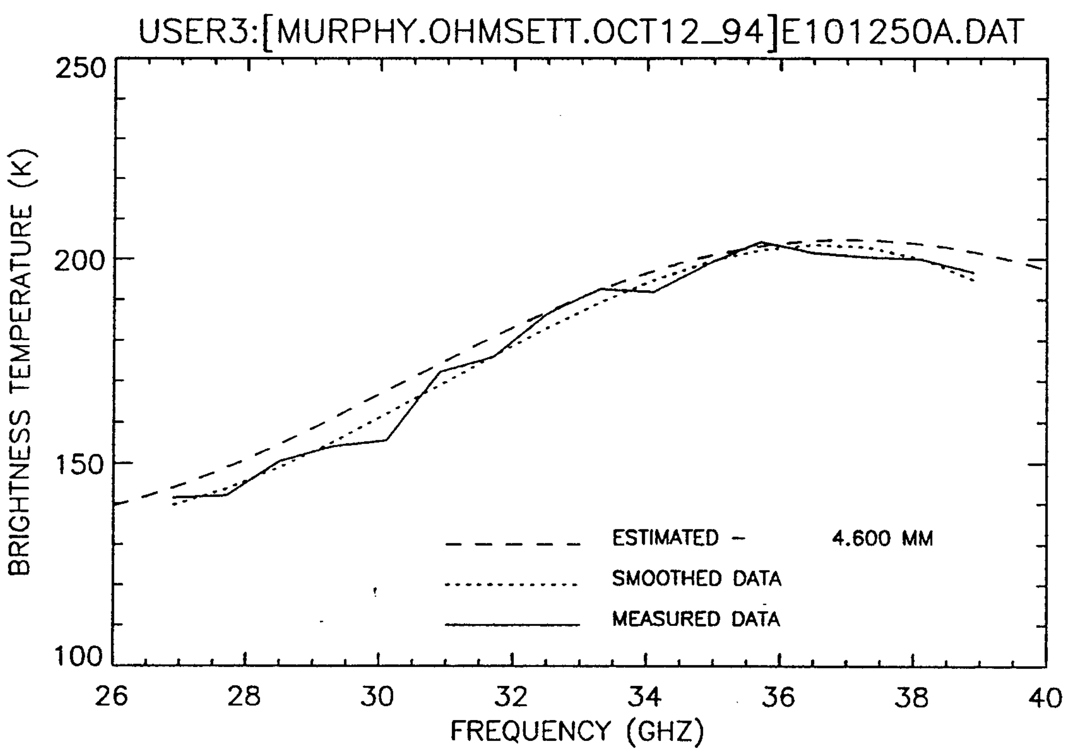

Figure C-38 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 1

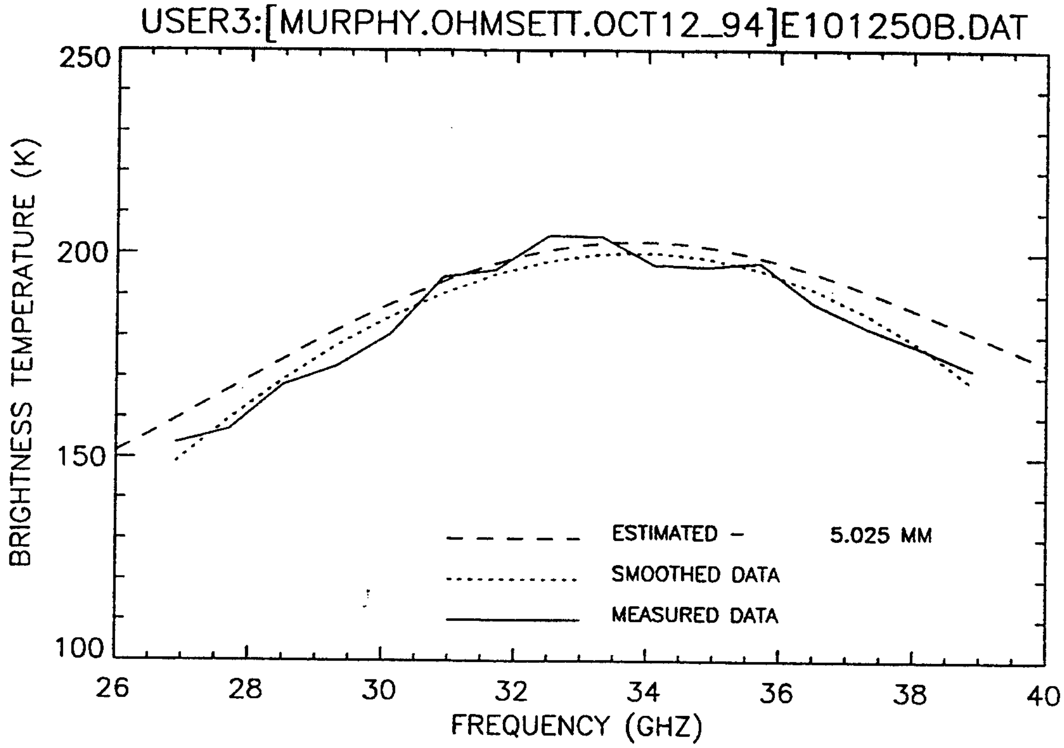

Figure C-39 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 2

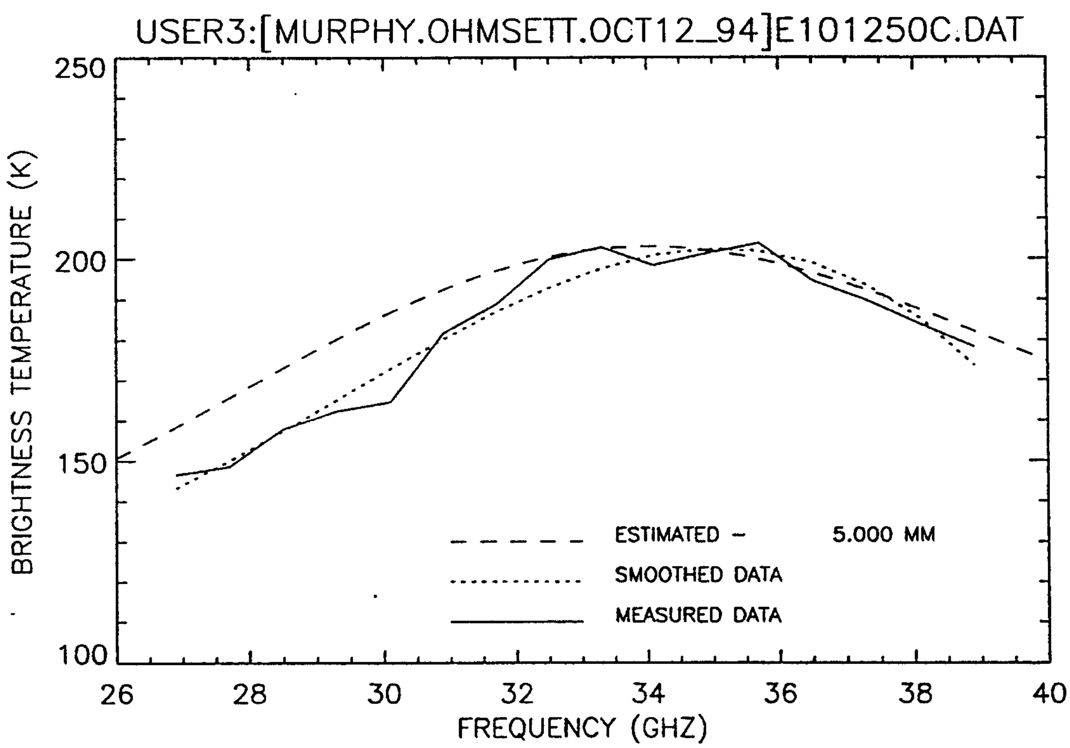

Figure C-40 T^B Versus Frequency Plot for 5.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 3

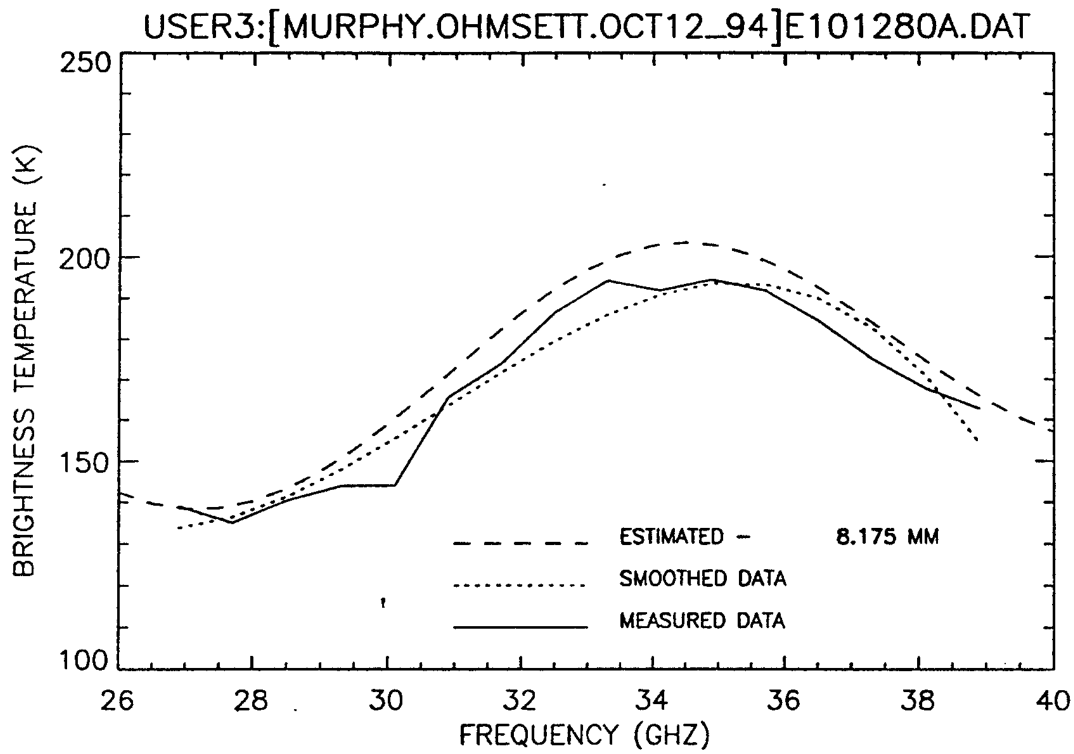

Figure C-41 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 1

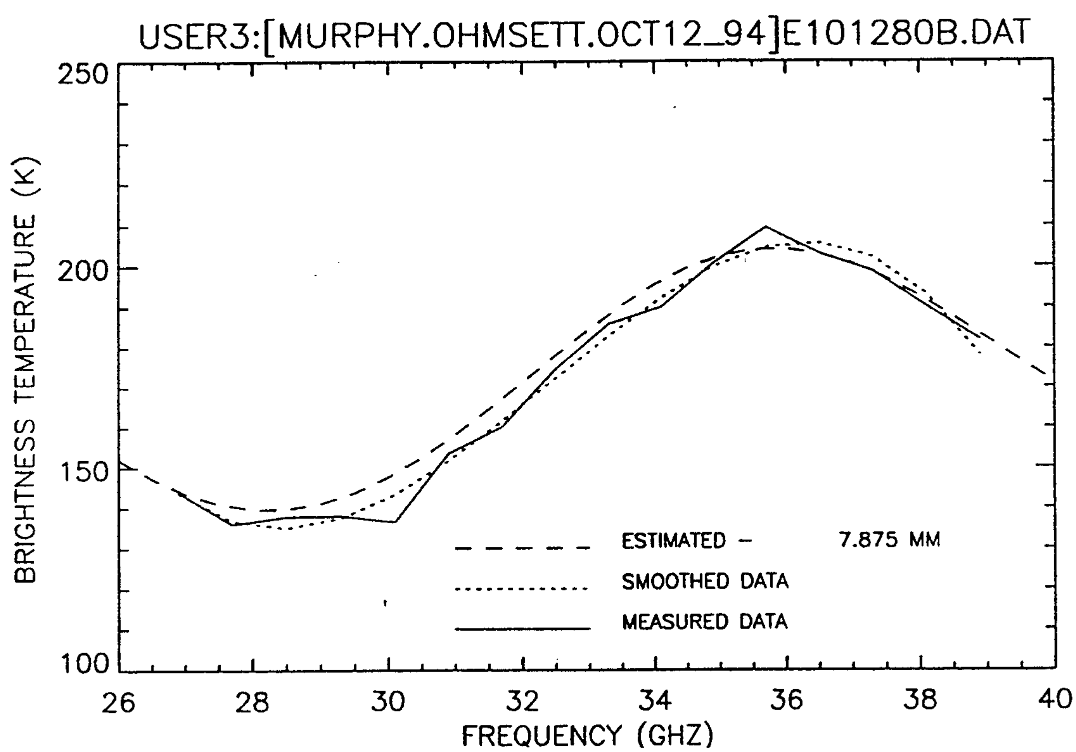

Figure C-42 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, Dyed Diesel, Calm Conditions, 12 October 1994, Pass 2

The files with the F-designation were collected under wave condition 1, small waves. The water reference file for these measurements is E101200A, which was a file collected earlier in the day.

F101280A - This curve is a good match to the algorithm estimate of 7.850 mm.

F101280B - This curve is a fair match to the algorithm estimate of 8.150 mm. The measured curve does have a shape similar to the estimate; there is an inflection point in the area of 36 GHz; however, the overall T^B amplitude modulation is not as large as would be expected.

F101280C - This curve is a poor match to the algorithm estimate of 0.600 mm. A better match is found in the range predicted by the correlation only result; in this case 7.900 mm (shown) is a fair match.

F101280D - This curve is a fair match to the algorithm estimate of 7.875 mm. The data points between 34 GHz and 36 GHz seem to have a much higher T^B than the theoretical prediction would account for.

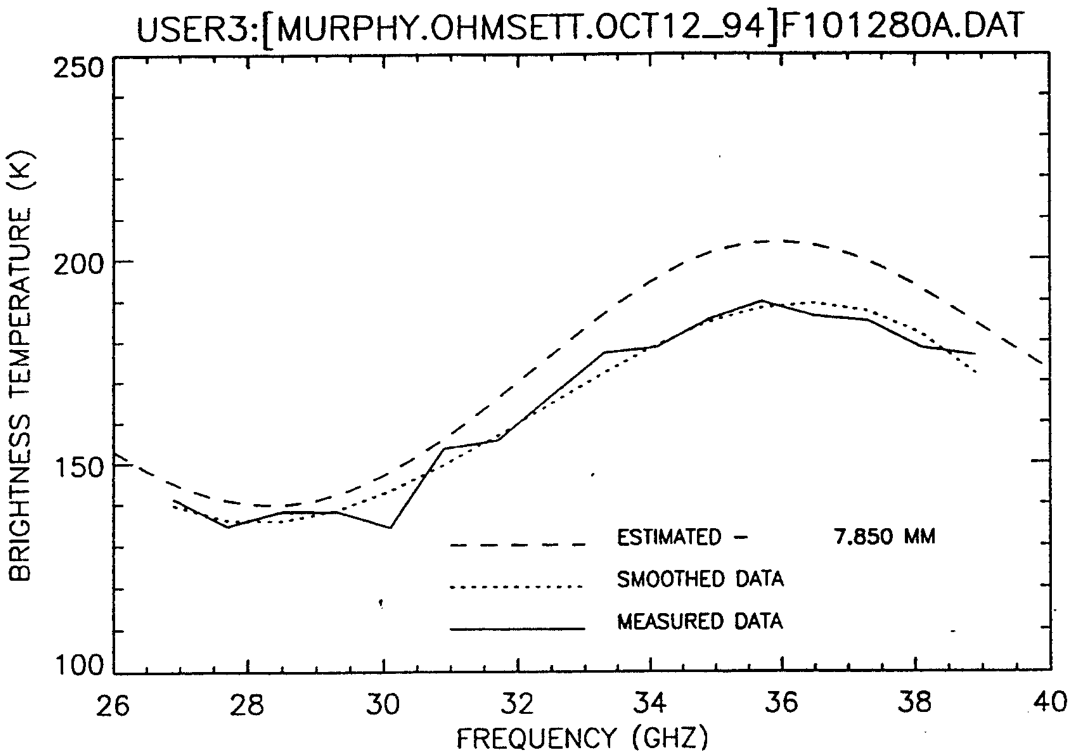

Figure C-43 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Small Wave Conditions, 12 October 1994, Pass 1

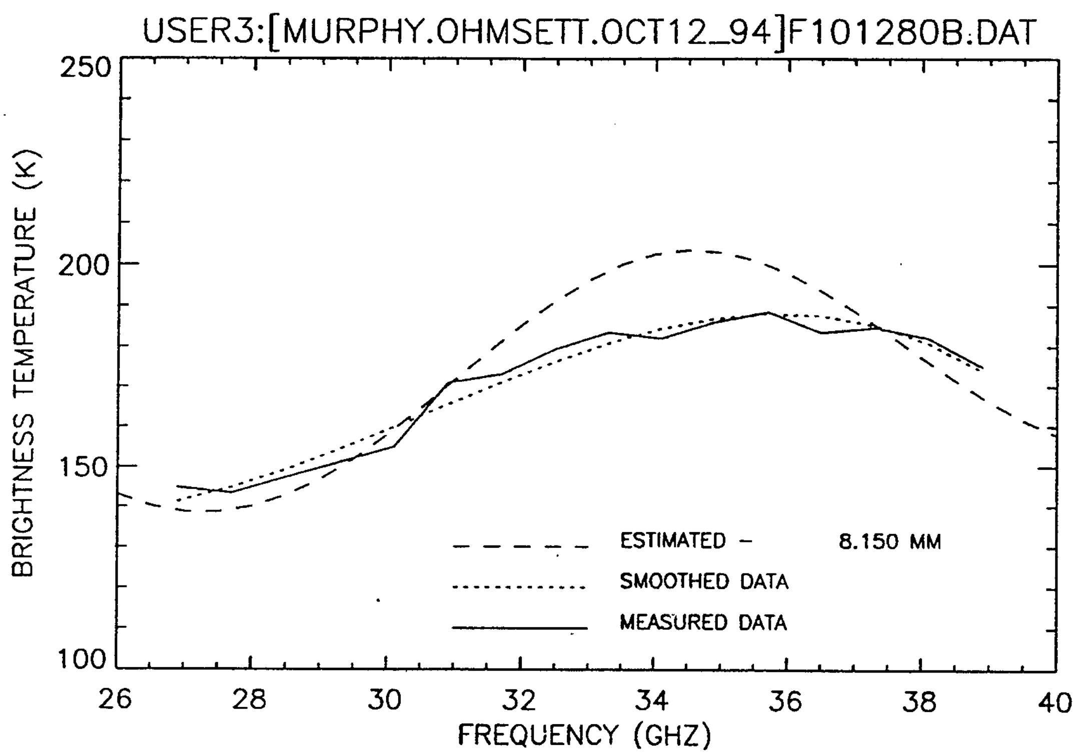

Figure C-44 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Small Wave Conditions, 12 October 1994, Pass 2

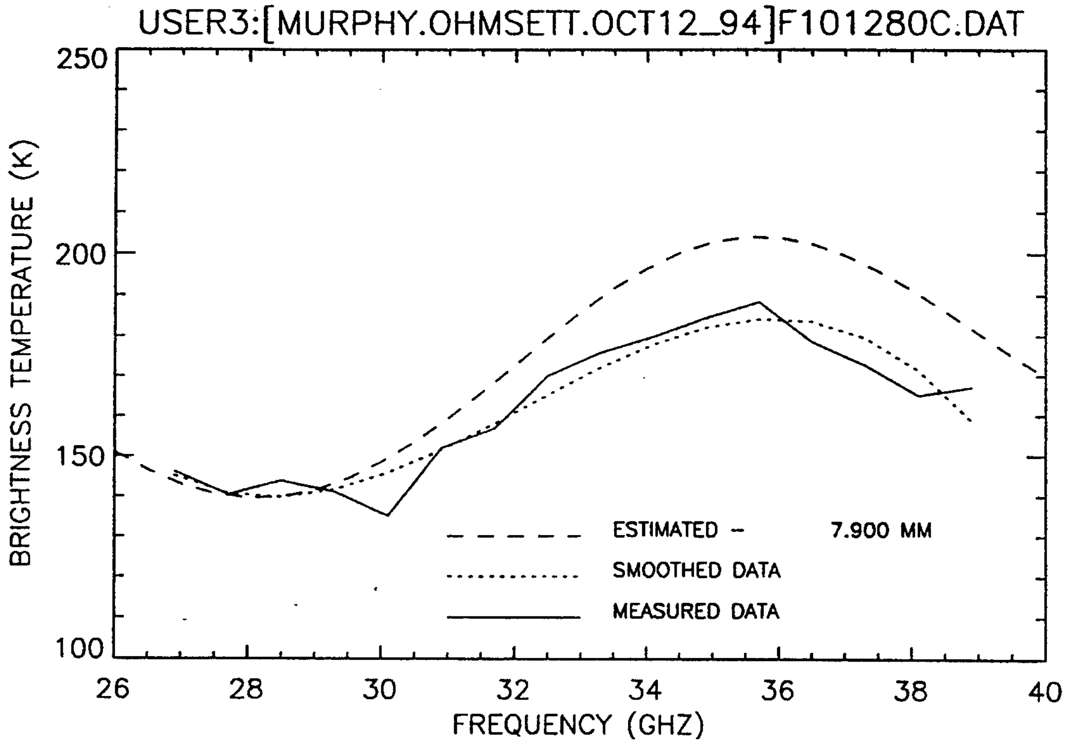

Figure C-45 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Small Wave Conditions, 12 October 1994, Pass 3

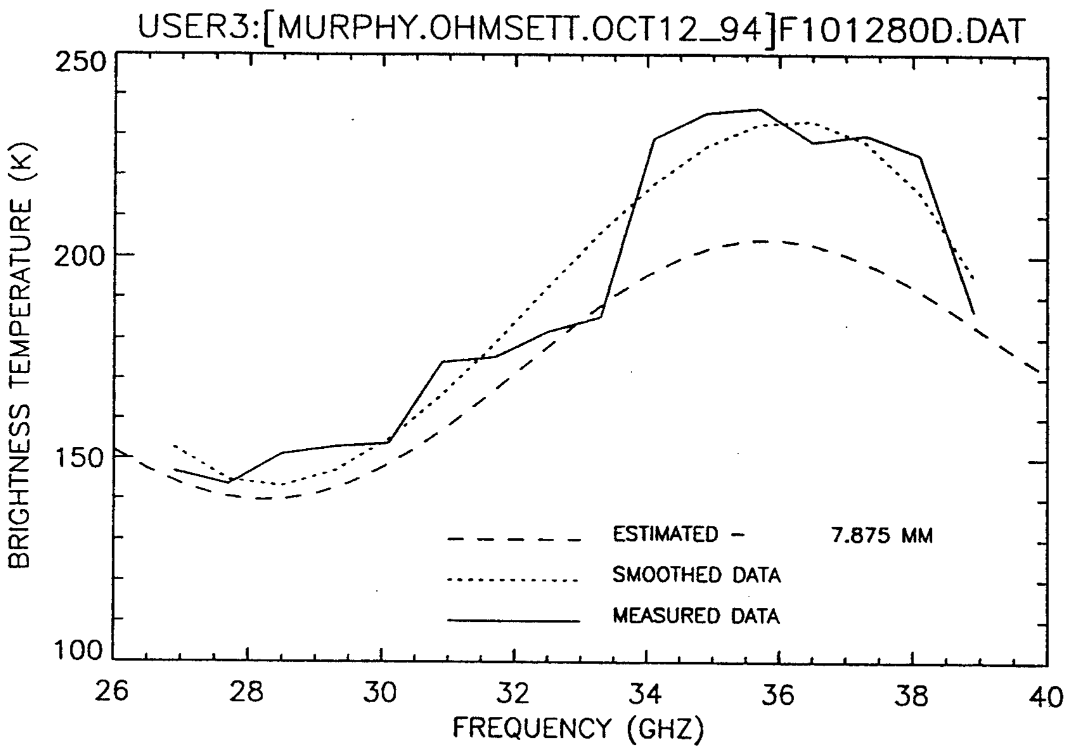

Figure C-46 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Small Wave Conditions, 12 October 1994, Pass 4

The G-designation files were collected under the wave 2 or medium wave conditions. Files G101280A and G101280B were collected at the very start of the larger wave train advancing into the oil target pools. Files G101280C through G101280H were collected after the waves had stirred up the oil; at this point air and water bubbles were noticeable on the surface of the oil target pool. OHMSETT down-looking videos were not collected during this dry-run collection so it is difficult to speculate why there is such a combination of good and poor results; however, the first two measurements (which best match the OHMSETT-reported oil thickness) were taken as the waves passed through the target. It is likely that these initial waves were not of the magnitude of the steady state waves encountered at the end of this sequence. Additionally, the oil surface was clear of entrapped bubbles at the start while the on-site note and photos indicate the presence of bubbles at the end. The inconsistent results which occured after the first two measurements may be due to the combination of wave-induced sun glint, which can cause spikes in T^B, and the presence of bubbles, which usually flatten the T^B versus frequency signature.

G101280A - This curve is a good match to the algorithm estimate of 6.775 mm although the measured curve does not exhibit as much amplitude variation as predicted by the theory.

G101280B - This curve is a good match to the algorithm estimate of 6.800 mm although the measured curve does not exhibit as much amplitude variation as predicted by the theory.

G101280C - This curve is a poor match to the algorithm estimate of 1.100 mm. The shape of the measured curve seems to match an estimate of 1.8 mm (shown); however, the overall T^B of the measured curve seems too low to support this hypothesis. The result is inconclusive.

G101280D - This curve does not match the algorithm estimate of 2.15 mm. It does not match any T^B curves, and does not appear to be an emulsion. The 8.0 mm theoretical curve is plotted here for comparison purposes. The result is inconclusive.

G101280E - This curve is a good match to the algorithm estimate of 0.975 mm.

G101280F - This curve is a good match to the algorithm estimate of 1.050 mm, although the measured curve does seem to have less slope (a flatter response) than the estimated curve.

G101280G - This curve is a good match to the algorithm estimate of 1.775 mm.

G101280H - This curve is a good-to-excellent match to the algorithm estimate of 1.675 mm.

The main bridge was positioned over the clear water pool for the following background water measurements.

G101200A - This curve was chosen as the water reference for this set of measurements.

G101200B - This curve is an excellent match to the algorithm estimate of 0.0 mm.

G101200C - This curve is an excellent match to a slightly warmer water background curve.

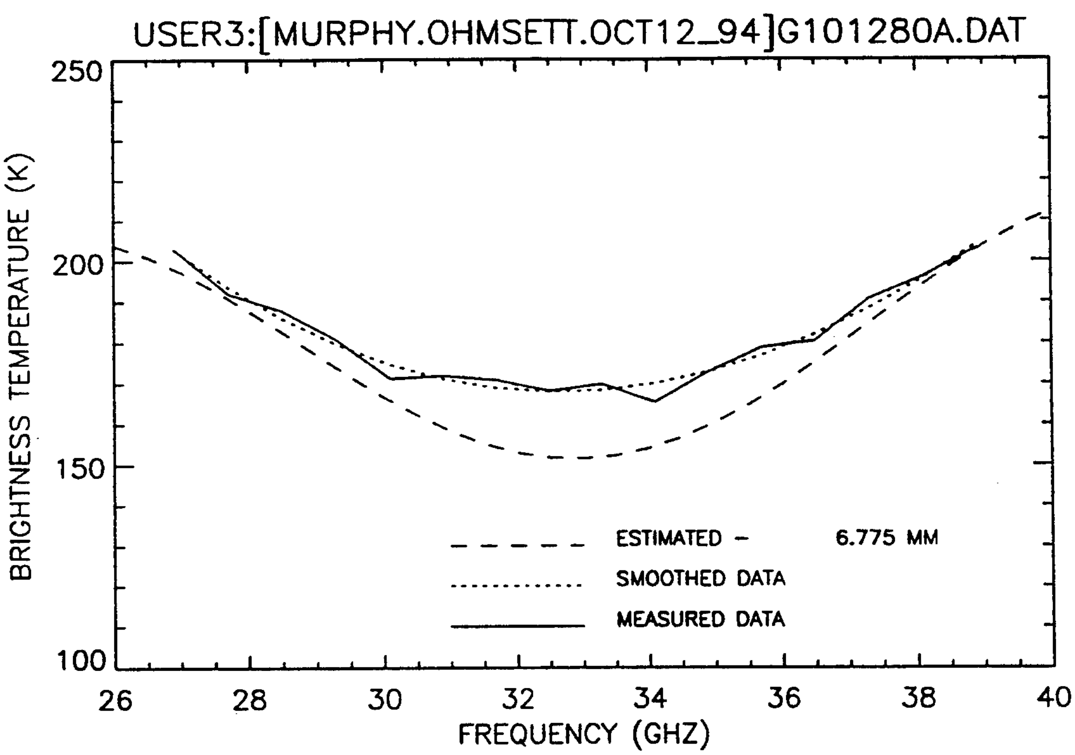

Figure C-47 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Medium Wave Conditions, 12 October 1994, Pass 1

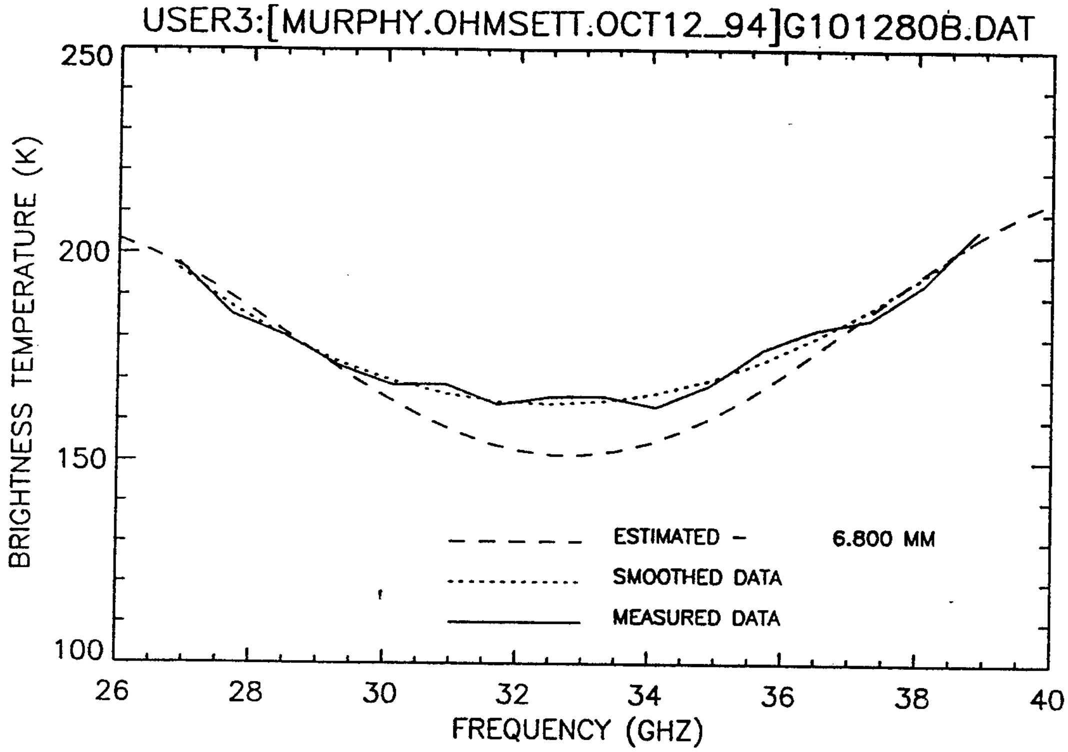

Figure C-48 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Medium Wave Conditions, 12 October 1994, Pass 2

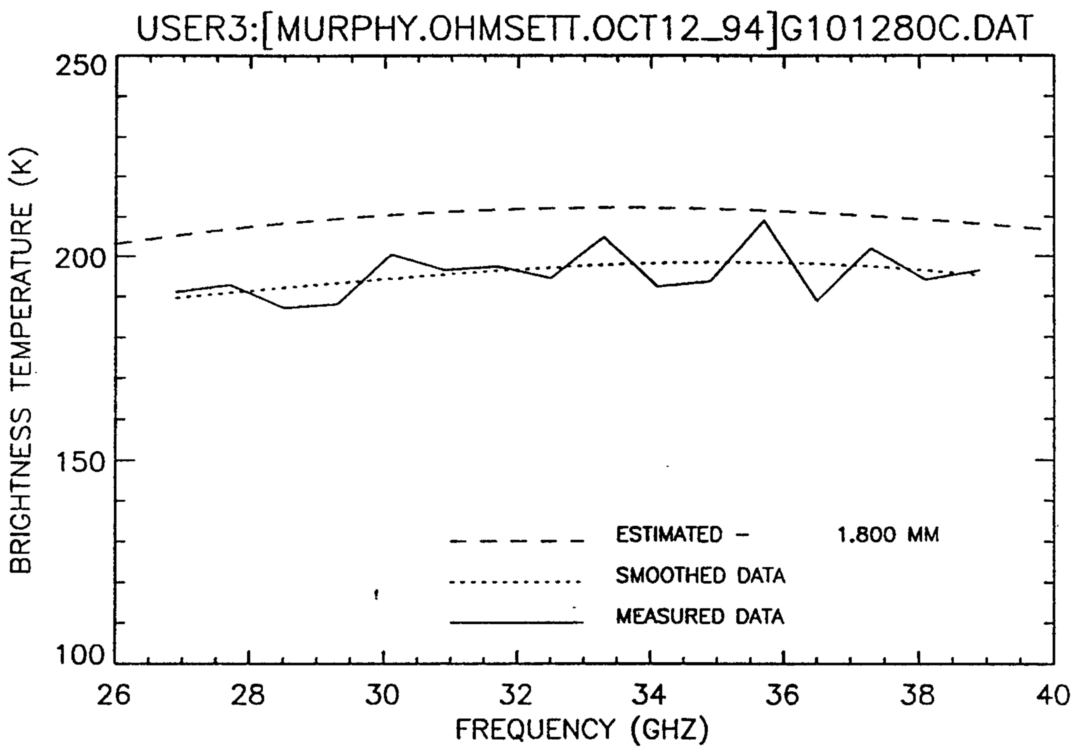

Figure C-49 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Medium Wave Conditions, 12 October 1994, Pass 3

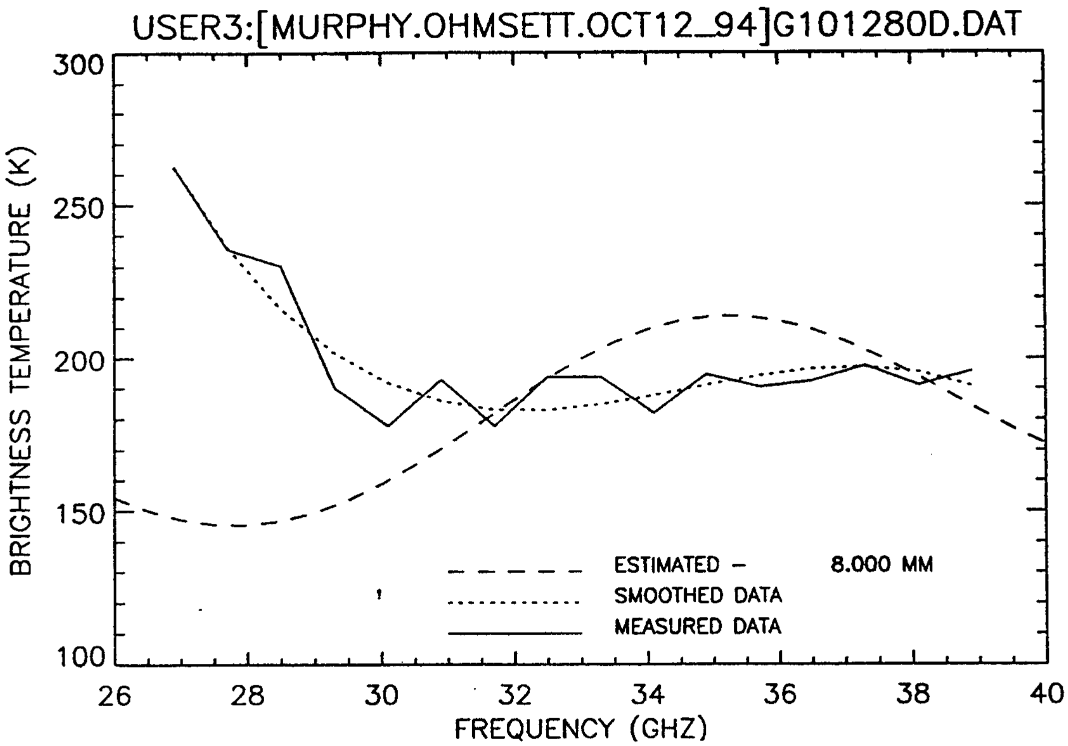

Figure C-50 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Medium Wave Conditions, 12 October 1994, Pass 4

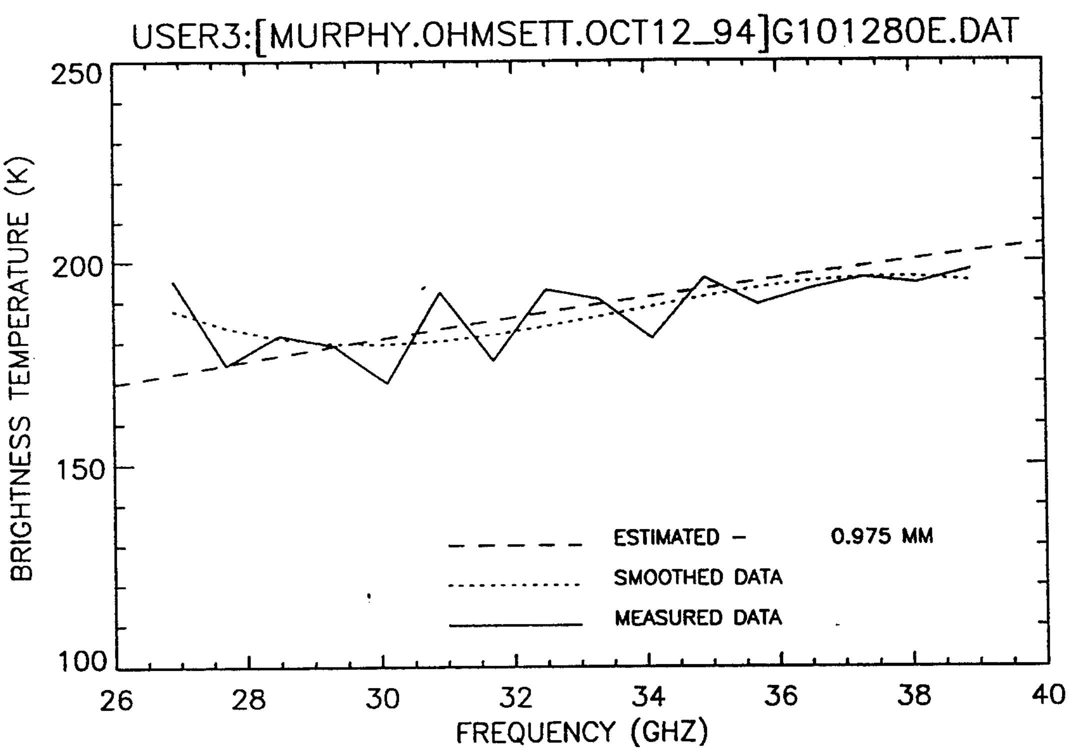

Figure C-51 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Medium Wave Conditions, 12 October 1994, Pass 5

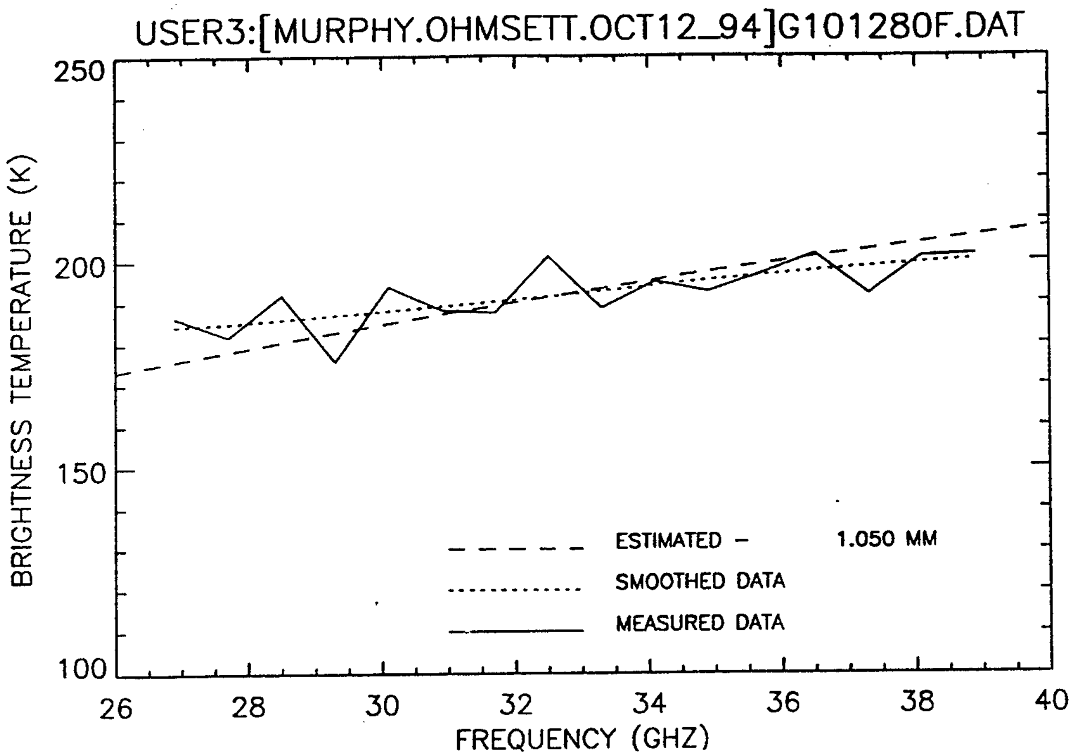

Figure C-52 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Medium Wave Conditions, 12 October 1994, Pass 6

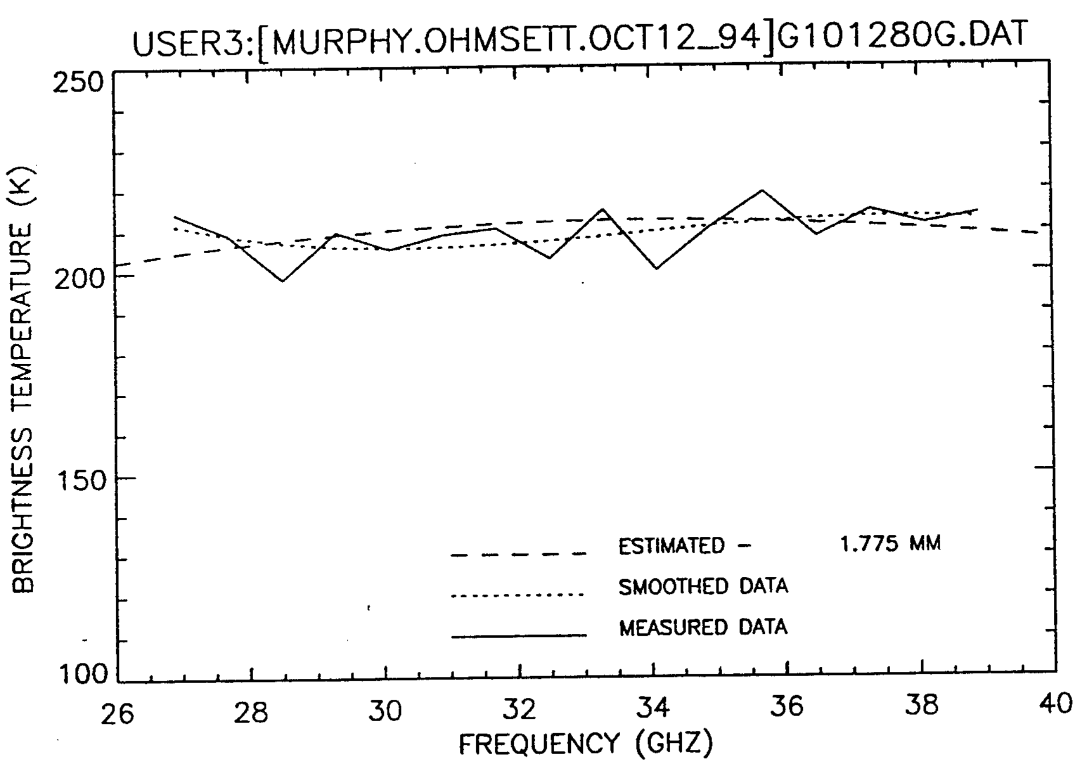

Figure C-53 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Medium Wave Conditions, 12 October 1994, Pass 7

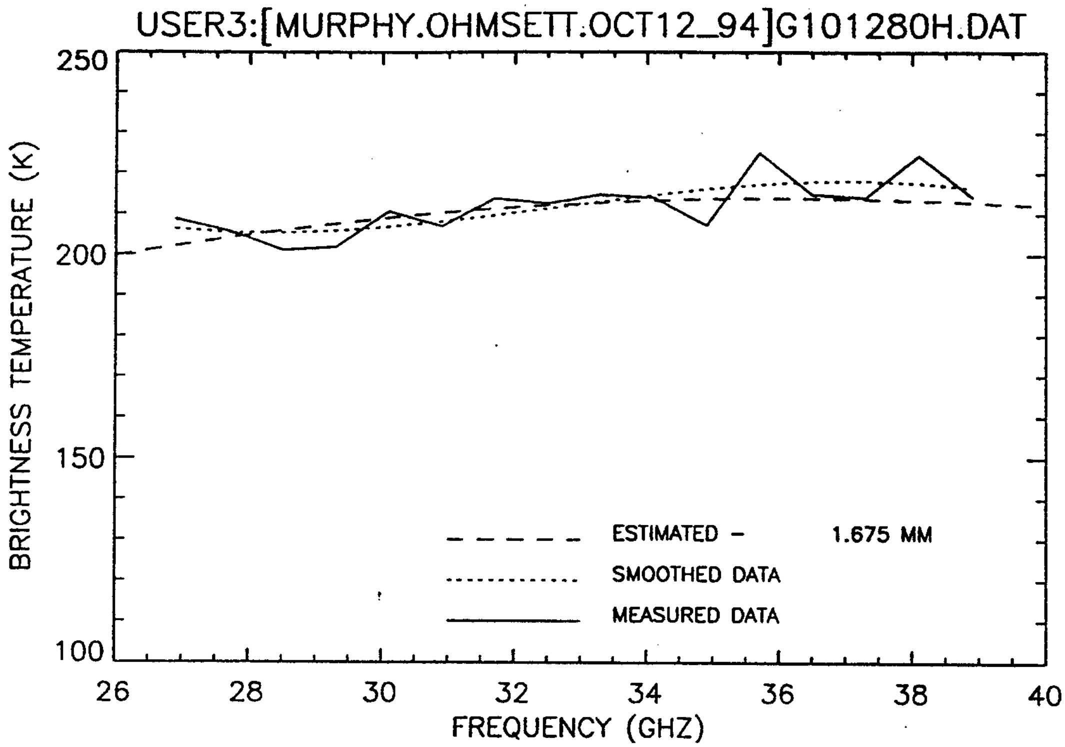

Figure C-54 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Medium Wave Conditions, 12 October 1994, Pass 8

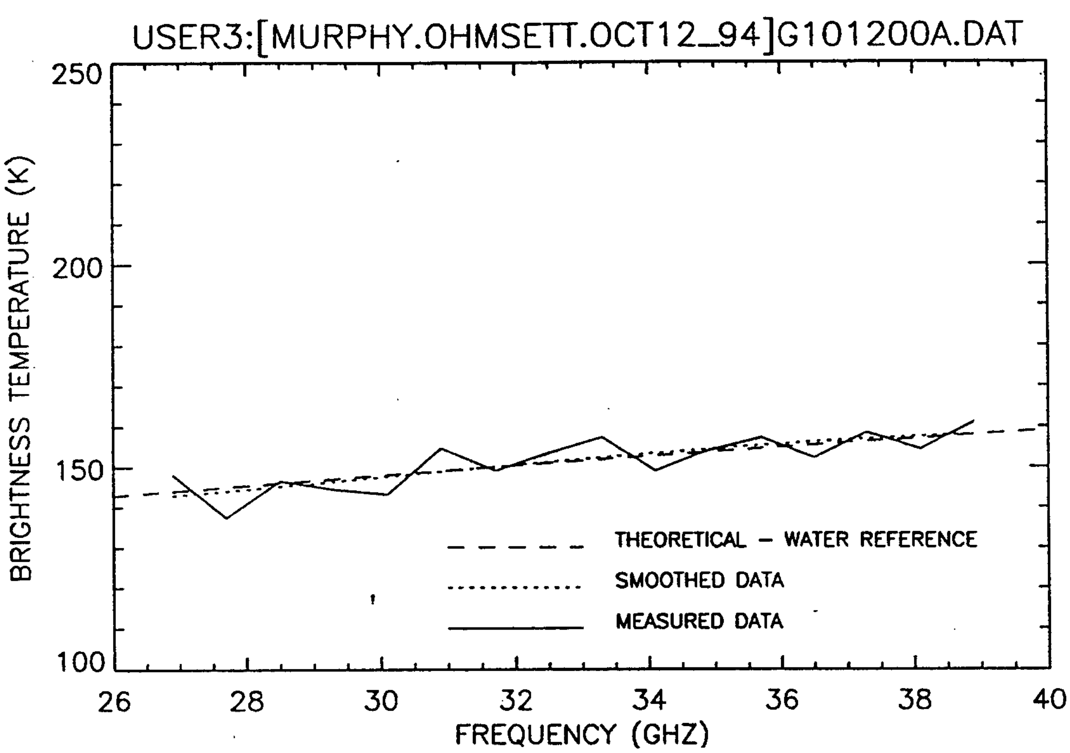

Figure C-55 T^B Versus Frequency Plot for Background Water, Medium Wave Conditions, 12 October 1994, Pass 1

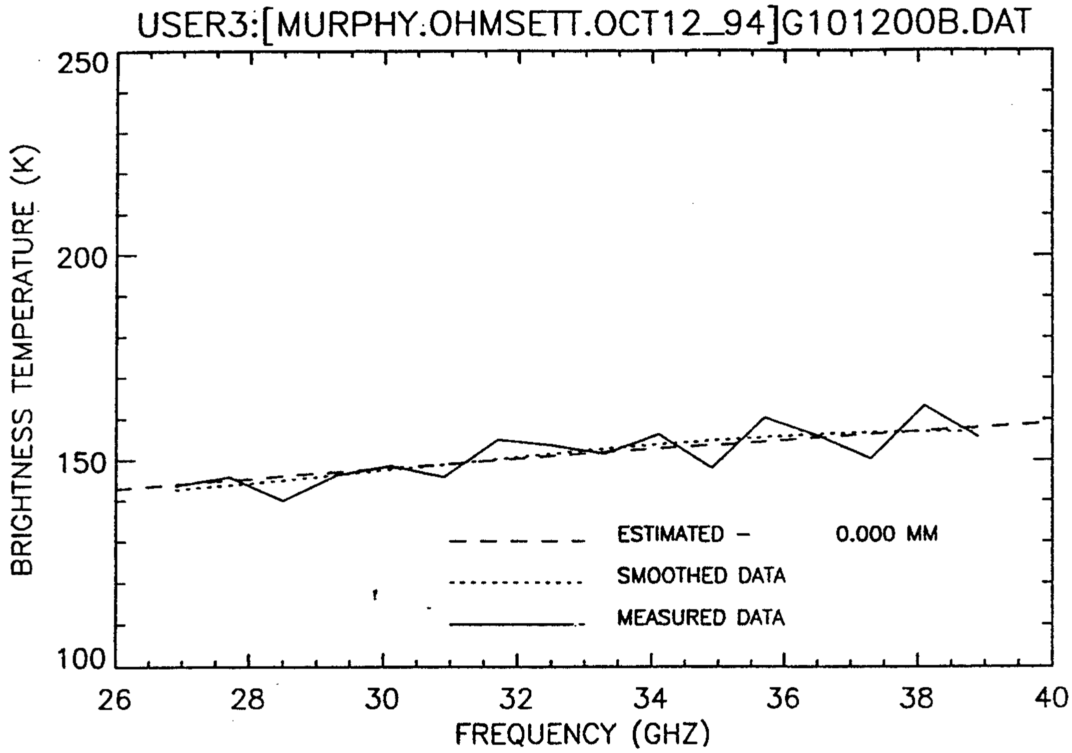

Figure C-56 T^B Versus Frequency Plot for Background Water, Medium Wave Conditions, 12 October 1994, Pass 2

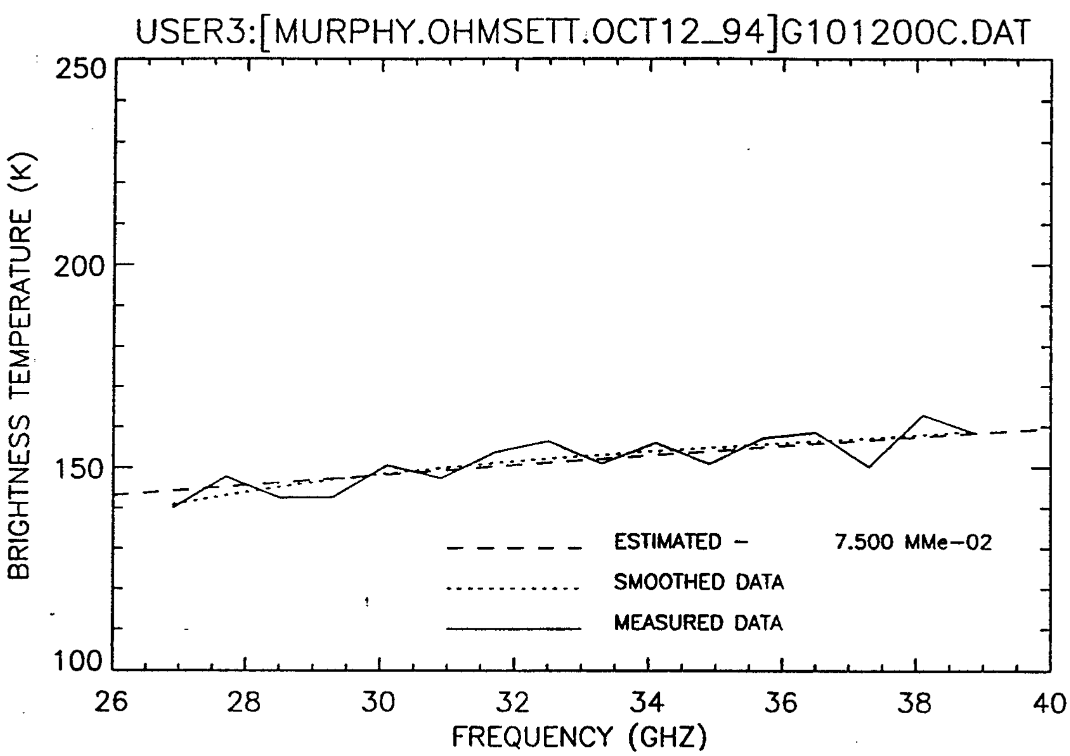

Figure C-57 T^B Versus Frequency Plot for Background Water, Medium Wave Conditions, 12 October 1994, Pass 3

APPENDIX D

BRIGHTNESS TEMPERATURE VERSUS FREQUENCY PLOTS FROM OHMSETT DYED DIESEL OIL TESTS

The frequency scanning radiometer was set up at the OHMSETT facility on the main equipment bridge with the oil pools in the radiometer antenna field of view. Tests were conducted on 13 and 14 October 1994 Measurements were conducted using dyed diesel oil, under two sets of wave conditions and two sets of chop conditions.

The file naming convention used for data files was cttxmmdd.DAT, where c is a letter identifier for the test session (U, V, W = 13 Oct. 94, H, I, J = 14 Oct. 94), tt is the thickness in tenths of a millimeter, x is the pass identifier, mm is the month (October = 10), and dd is the day. Thus H101480C.DAT was the third pass collected on 14 October 1994 using an oil film thickness of 8.0 mm.

The plots shown in this appendix, figures D-1 through D-145, are radiometric brightness temperature (T^B), expressed in Kelvin (K), as measured by the FSR, versus the measurement frequency in GHz. Under the current FSR software configuration, sixteen equally spaced points between 26.5 GHz and 40.0 GHz are sampled, with each sample period somewhat less than one second. These sixteen points are plotted as 'measured' points. For each data set, the oil thickness estimation algorithm, described in Chapter 4, is used to estimate an oil film thickness. This algorithm-derived estimate is displayed with the smoothed curve and the declared result plotted over the actual measured points. The data analyst can then either choose to accept the algorithm estimate, or manually select a curve that may be a better fit to the measured data.

The plots in this appendix are arranged by test session. At the beginning of each test session data set, comments are provided for each measurement concerning the fit of the algorithm estimate and the analyst's choice for each curve's best fit.

When viewing the plots, it is important to understand that the figure titles cite only the target oil thickness value within the test pool being viewed. As described in

chapter 3, the actual thickness of oil being viewed by the FSR at any given moment could vary substantially from this target value.

U101300A- This is the water reference that was chosen for this set of measurements.

U101300B - This curve is a good match to the algorithm estimate of 0.0 mm.

U101300C - This curve is a good match to the algorithm estimate of 0.0 mm.

U101305A - This curve is a good match to the algorithm estimate of 0.475 mm.

U101305B - This curve is a good match to the algorithm estimate of 0.550 mm.

At this point, a glitch, thought to be generated by the HPIB interface, caused the laptop to lock-up. At this point, the laptop software was restarted and the HPIB equipment reset.

U101305C - This curve is a good match to the algorithm estimate of 0.525 mm.

During the collection, the measured T^B versus frequency were plotted on the laptop computer screen. The following curves are examples of cases where the FSR operator commented on a good match with the 2.0 mm theoretical prediction.

U101310A -This curve is a poor match to the algorithm estimate of 2.2 mm. This curve does not match well to a 1.0 mm estimate; however, the shape seems to match the 1.85 mm estimate best, although the overall T^B temperature seems too low.

U101310B -This curve is a poor match to the algorithm estimate of 2.3 mm. The curve also does not match well to a 1.0 mm estimate; the shape seems to match the shape of a 1.8 - 1.9 mm range best, although overall T^B seems too low.

The OHMSETT main bridge was moved so that the FSR could measure a different part of the oil target. For the following measurements the FSR operator commented that the measurements seemed to match a 1.0 mm estimate well.

U101310C - This curve is a fair match to the algorithm estimate of 1.0 mm. The shape seems to match a 1.7 mm estimate (a 1.7 mm estimate is shown plotted for U101310D) somewhat better due to the slight curvature in the measured curve.

U101310D - This curve is a fair match to the algorithm estimate of 1.075 mm; the 1.075 mm curve is quite similar to the 1.0 mm curve plotted for U101210C. The shape might match a 1.7 mm estimate (plotted) somewhat better due to the slight curvature in the measured curve.

For the following measurements the FSR operator commented that the measurements seemed to match a 3.0 mm estimate well.

U101320A - This is a good match to algorithm estimate of 3.175 mm. This curve does not exhibit any characteristics of a 2.0 mm theoretical prediction, which is a slight downward slope with a high (200+° K) brightness temperature over the entire band.

The OHMSETT bridge was moved to a new position for the FSR to measure a different area in the oil target pool.

U101320B - This curve is a good match to the algorithm estimate of 3.15 mm. This curve does not exhibit any characteristics of a 2.0 mm theoretical prediction, which is a slight downward slope with a high (200+° K) brightness temperature over the entire band.

At this point, the laptop computer crashed again, and the FSR system was reset/restarted.

U101320C - This curve is a fair match to the algorithm estimate of 2.675 mm. This estimate seems like the best choice, although a 2.3 mm estimate would also be good based on the shape of the measured curve; however the mean T^B does not match very well.

U101320D - This curve is a good match to the algorithm estimate of 3.0 mm.

The OHMSETT bridge was moved to south end of 2.0 mm pool. The oil target at this end of the pool looked thinner.

U1013221 - This curve is a fair match to the algorithm estimate of 2.625 mm based on the mean T^B value. The shape seems to match a 2.1 mm curve well, but in this case the mean T^B value would be too low.

Most 3.0 mm files were lost due to a file naming convention error that occurred after another computer crash, again due to glitch. The 3.0 mm oil target measurements that were lost were made at the center and north end of the pool. For the following measurement, the OHMSETT bridge had moved to the south end of the target pool. The FSR operator commented that the following measurement was a good match to 4.0 mm. Based on visual observation, the oil film appeared thicker at this end of the pool.

U1013230 - This curve is a fair match to the algorithm estimate of 3.600 mm. The range of curves from 3.4 - 3.9 mm all seem to match well.

More 8.0 mm files were lost due to the same file naming convention error.

U1013280 - This curve is a good match to the algorithm estimate of 9.875 mm based on the shape of the curve. The amplitude variation of the measurement seems low compared to that of the theoretical prediction.

Many of the raw 8.0 mm data sets matched the theoretical T^B versus frequency curves better than the smoothed polynomial fitting function. This is because the

polynomial function fits a least-squares, third order polynomial curve to the raw data, while at 8 mm oil thickness, the T^B versus frequency relationship becomes distinctly sinusoidal over the 26 to 40 GHz FSR band. Future algorithm development should explore sinusoidal fitting functions, but the polynomial function was judged to be adequate for most of the data collected during this test.

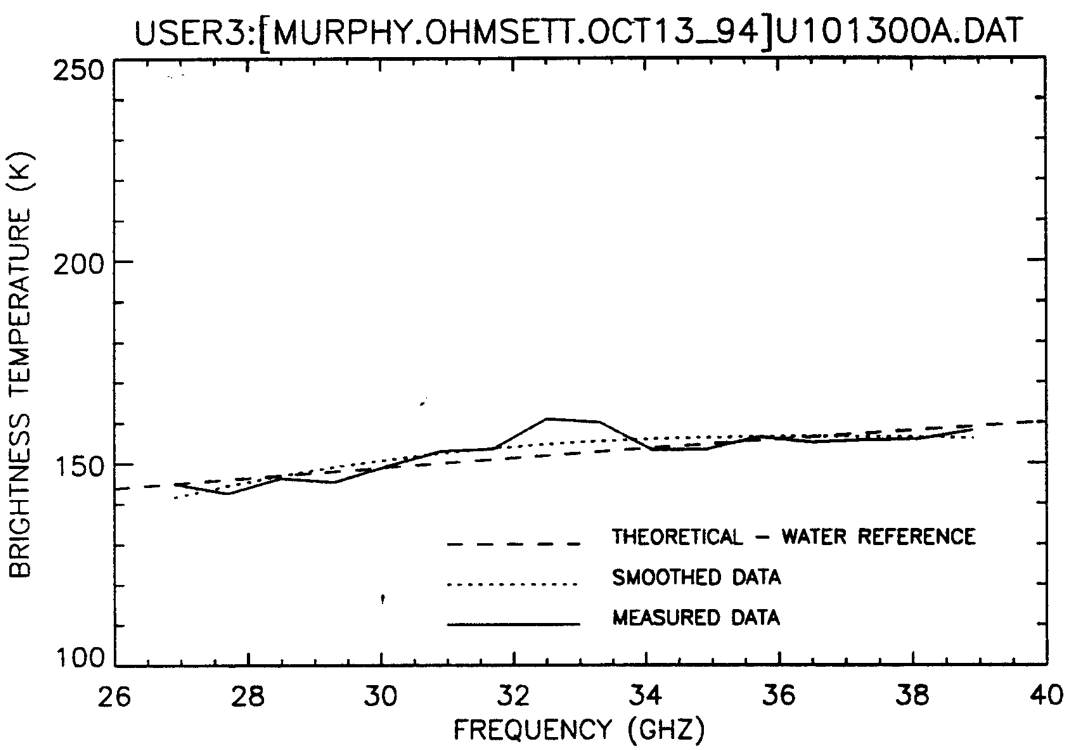

Figure D-1 T^B Versus Frequency Plot for Background Water, 13 October 1994, Pass 1

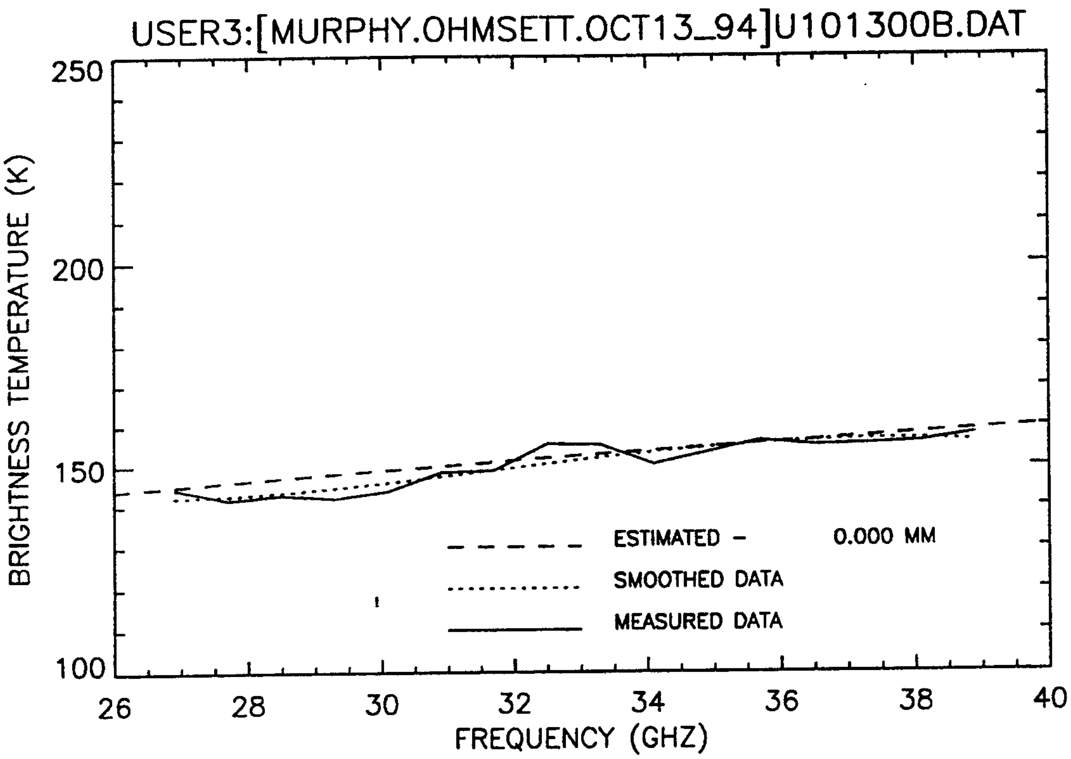

Figure D-2 T^B Versus Frequency Plot for Background Water, 13 October 1994, Pass 2

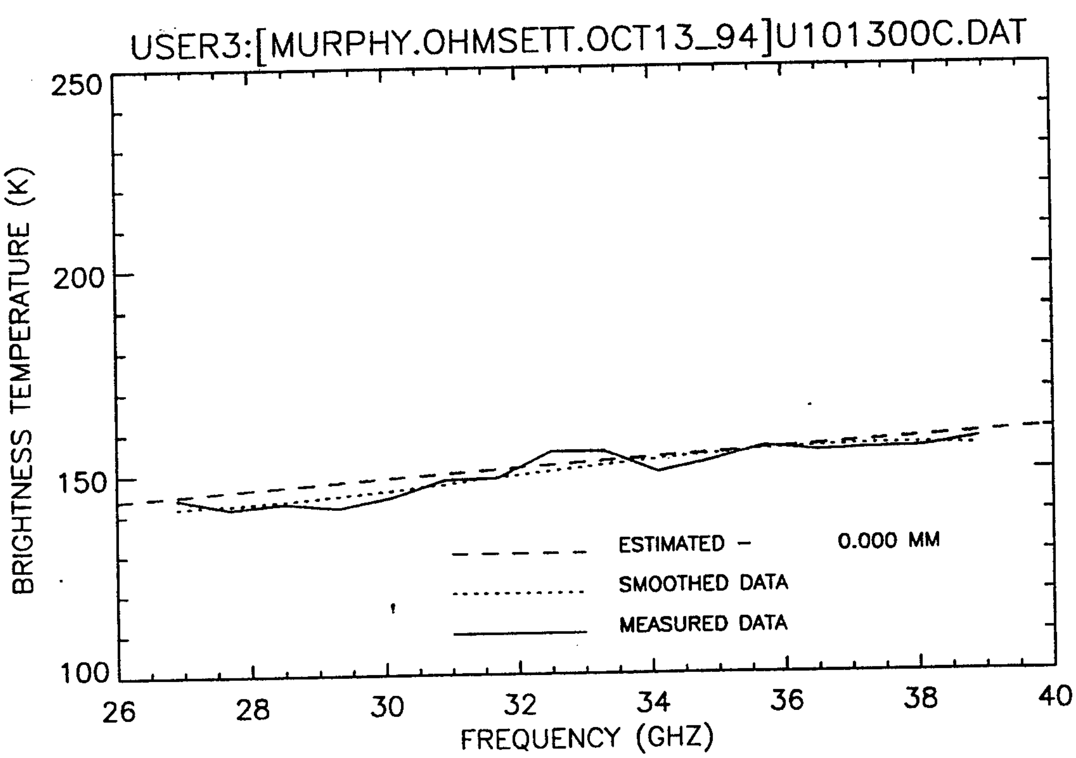

Figure D-3 T^B Versus Frequency Plot for Background Water, 13 October 1994, Pass 3

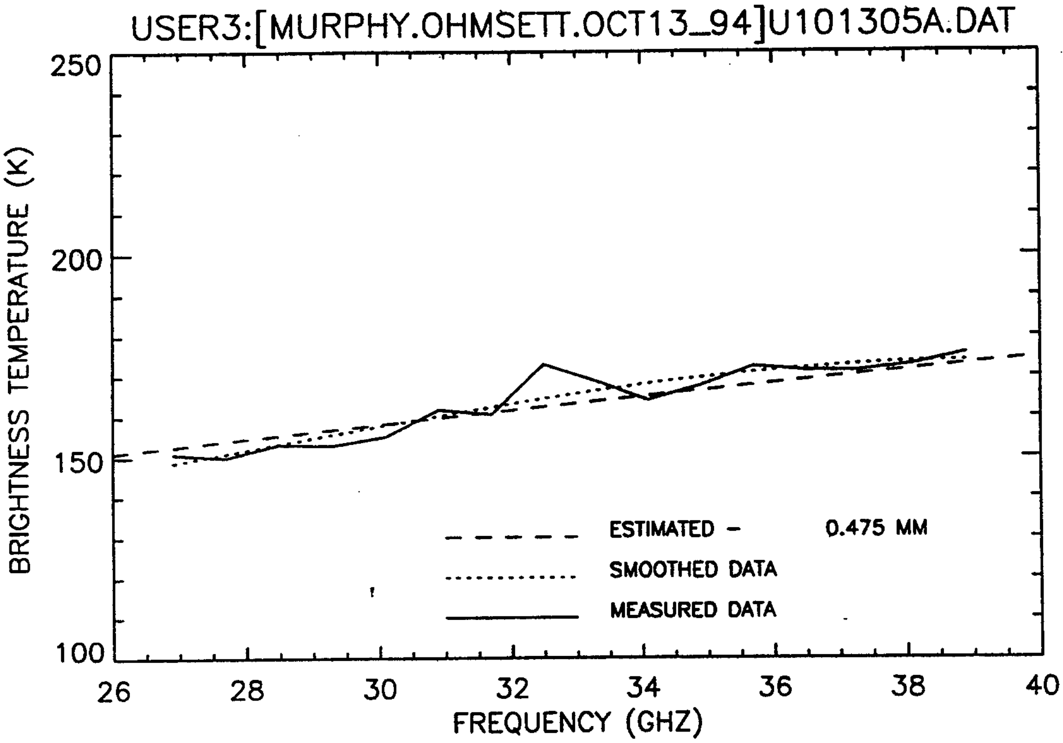

Figure D-4 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, Dyed Diesel, 13 October 1994, Pass 1

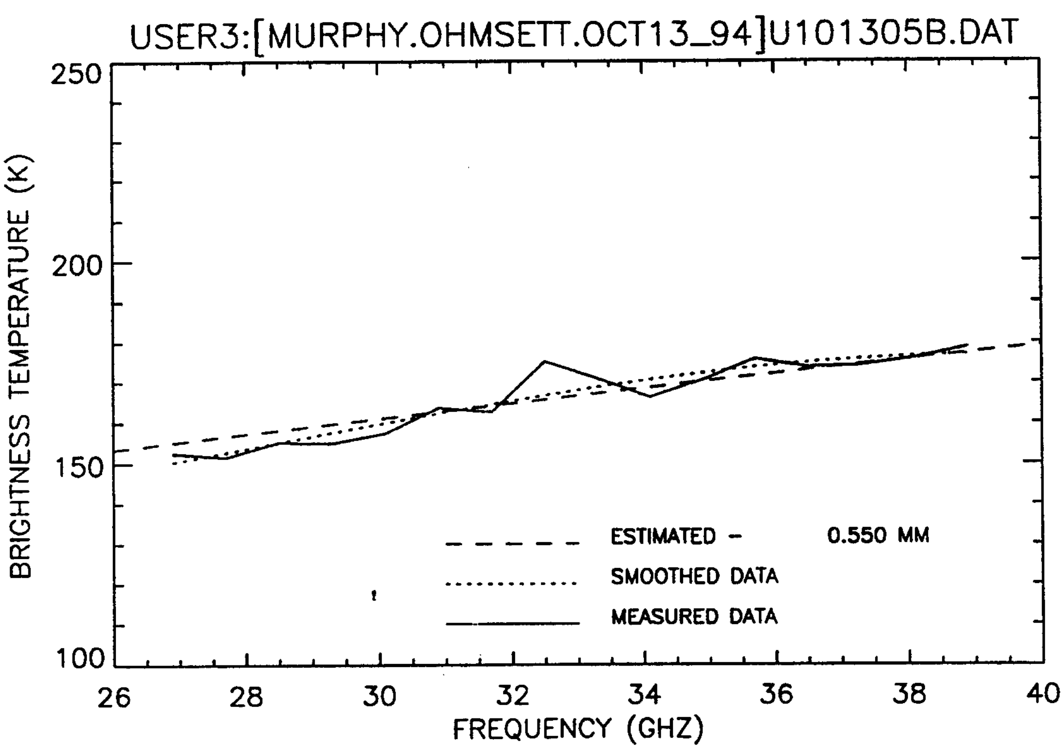

Figure D-5 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, Dyed Diesel, 13 October 1994, Pass 2

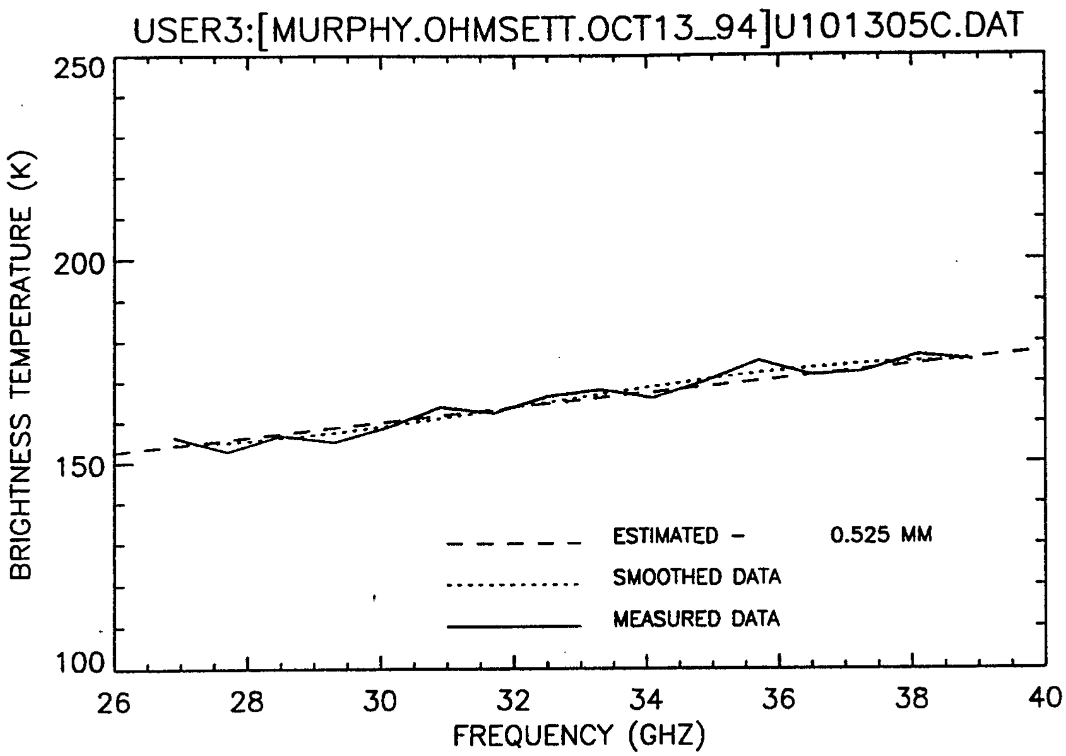

Figure D-6 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, Dyed Diesel, 13 October 1994, Pass 3

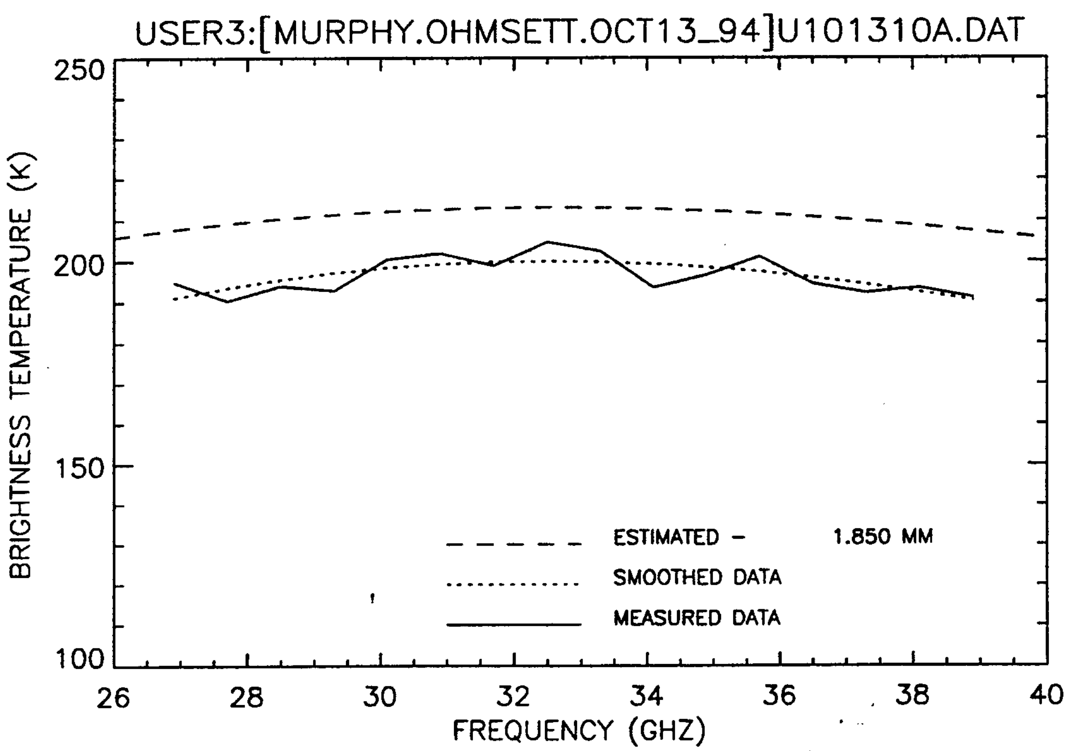

Figure D-7 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, Dyed Diesel, 13 October 1994, Pass 1

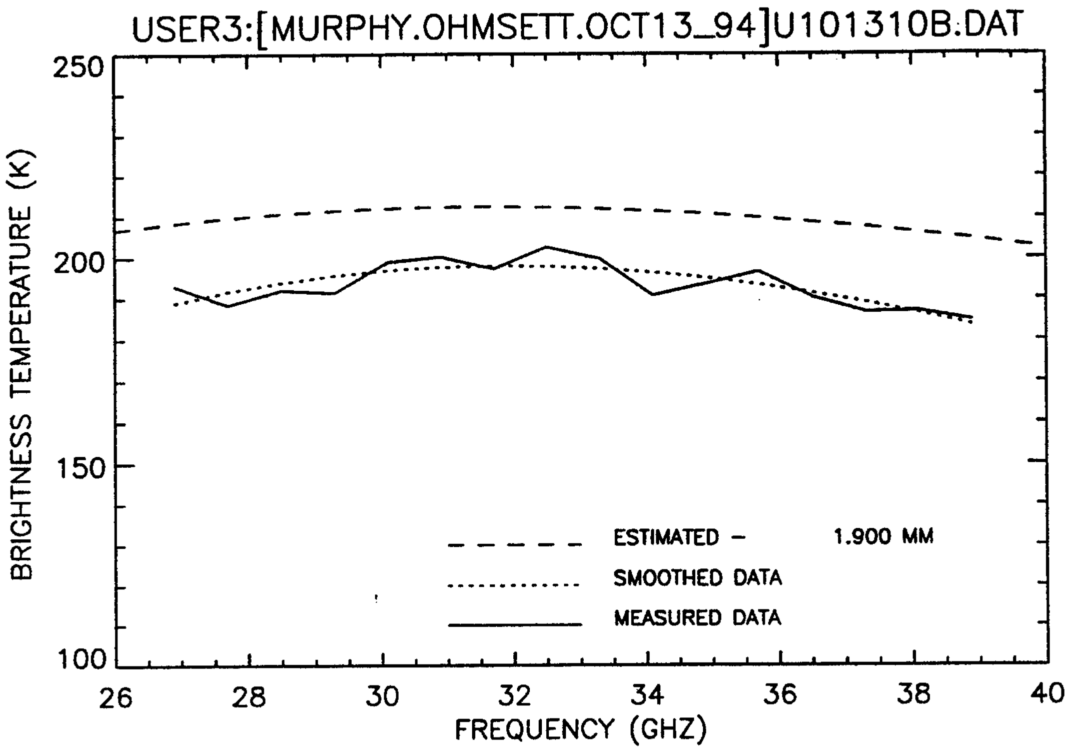

Figure D-8 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, Dyed Diesel, 13 October 1994, Pass 2

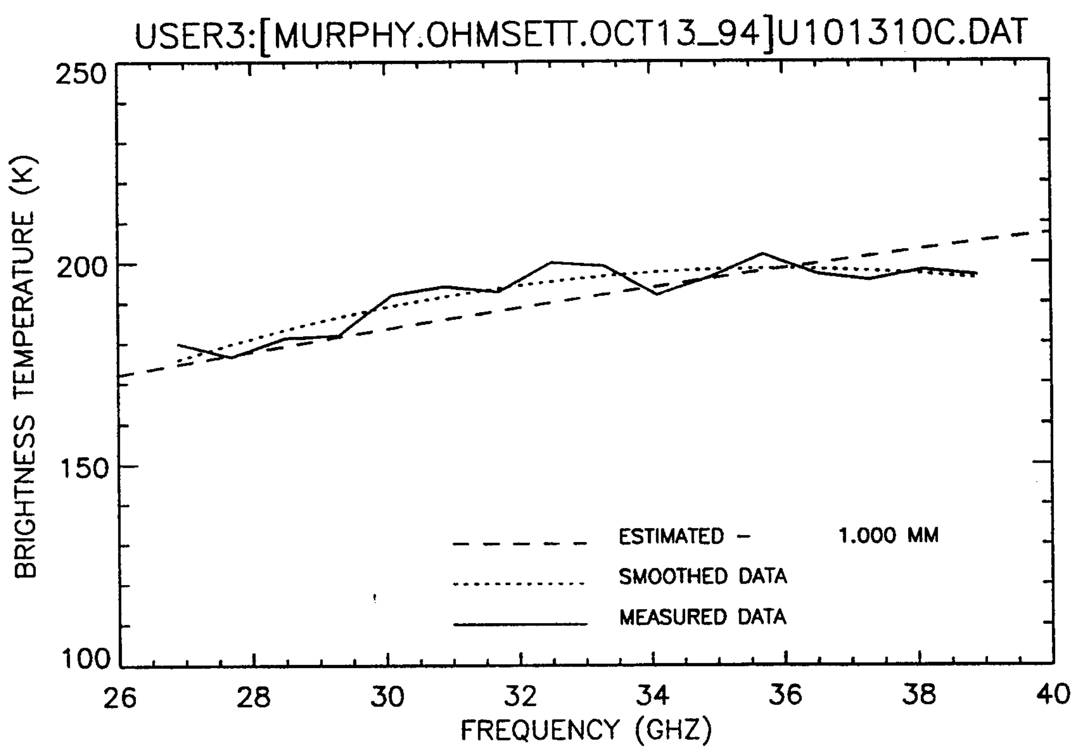

Figure D-9 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness,

Dyed Diesel, 13 October 1994, Pass 3

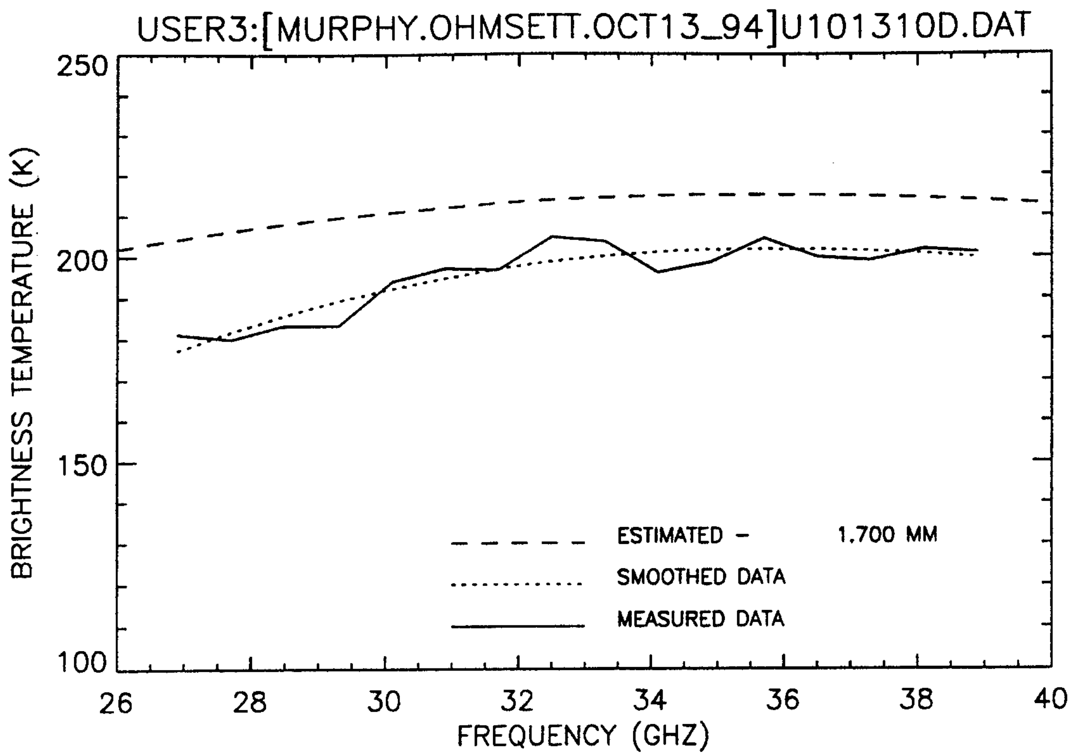

Figure D-10 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, Dyed Diesel, 13 October 1994, Pass 4

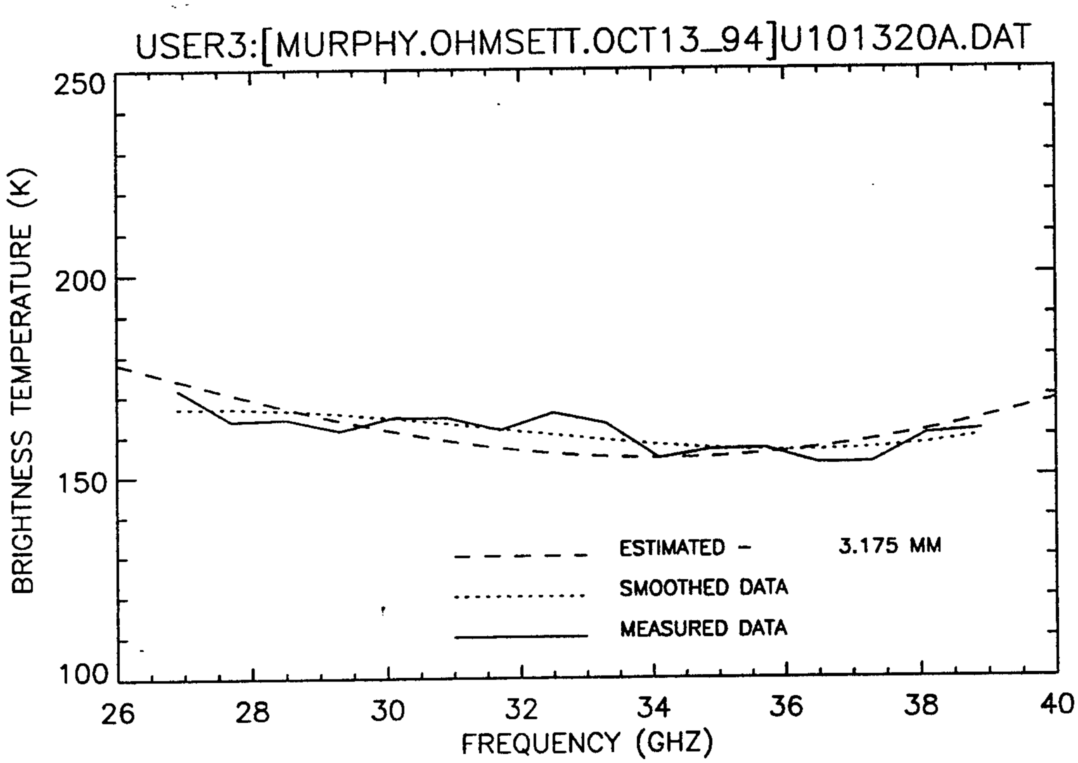

Figure D-11 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, Dyed Diesel, 13 October 1994, Pass 1

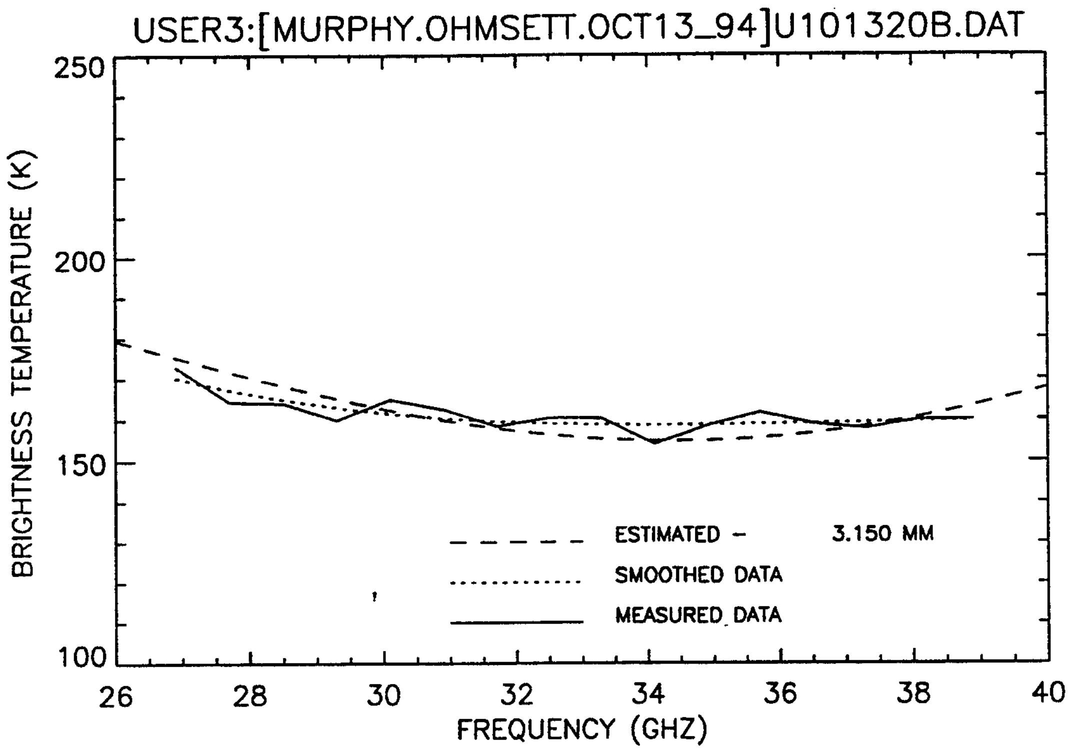

Figure D-12 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, Dyed Diesel, 13 October 1994, Pass 2

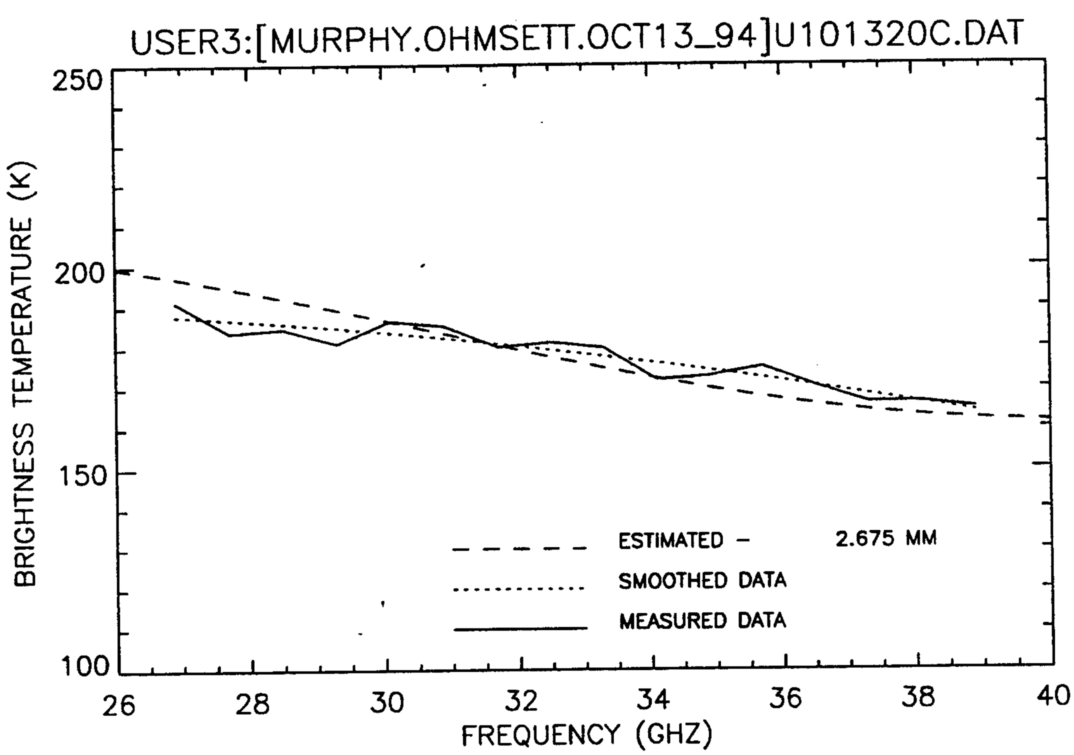

Figure D-13 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, Dyed Diesel, 13 October 1994, Pass 3

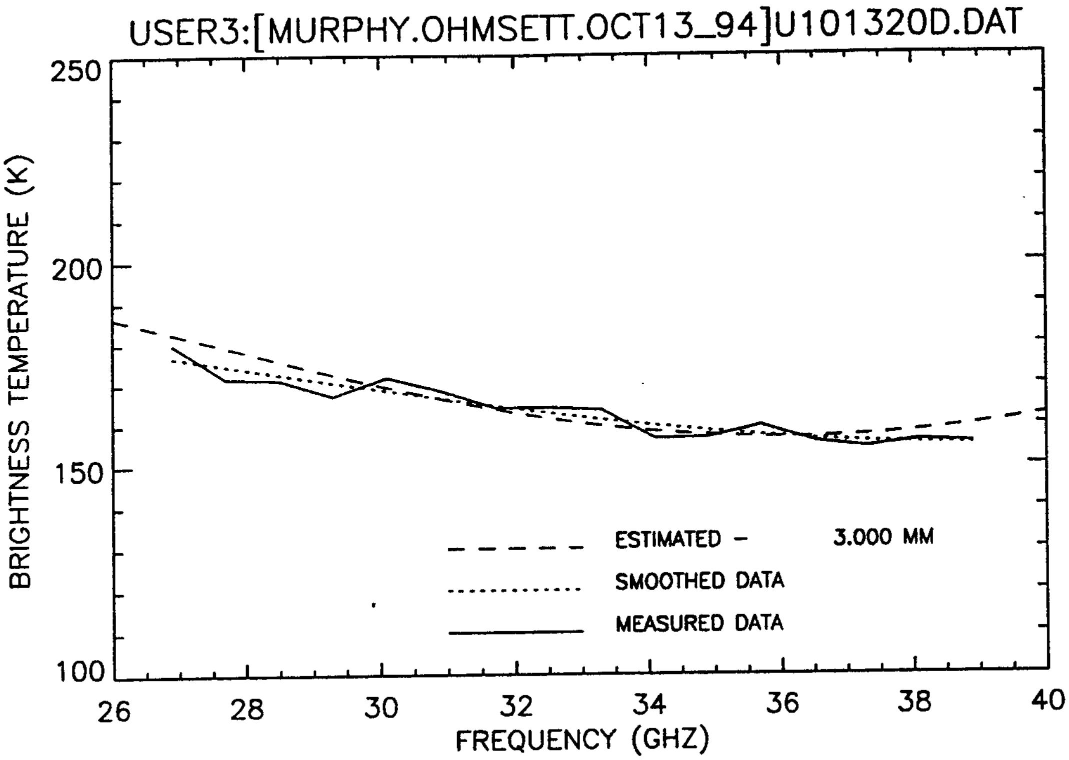

Figure D-14 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, Dyed Diesel, 13 October 1994, Pass 4

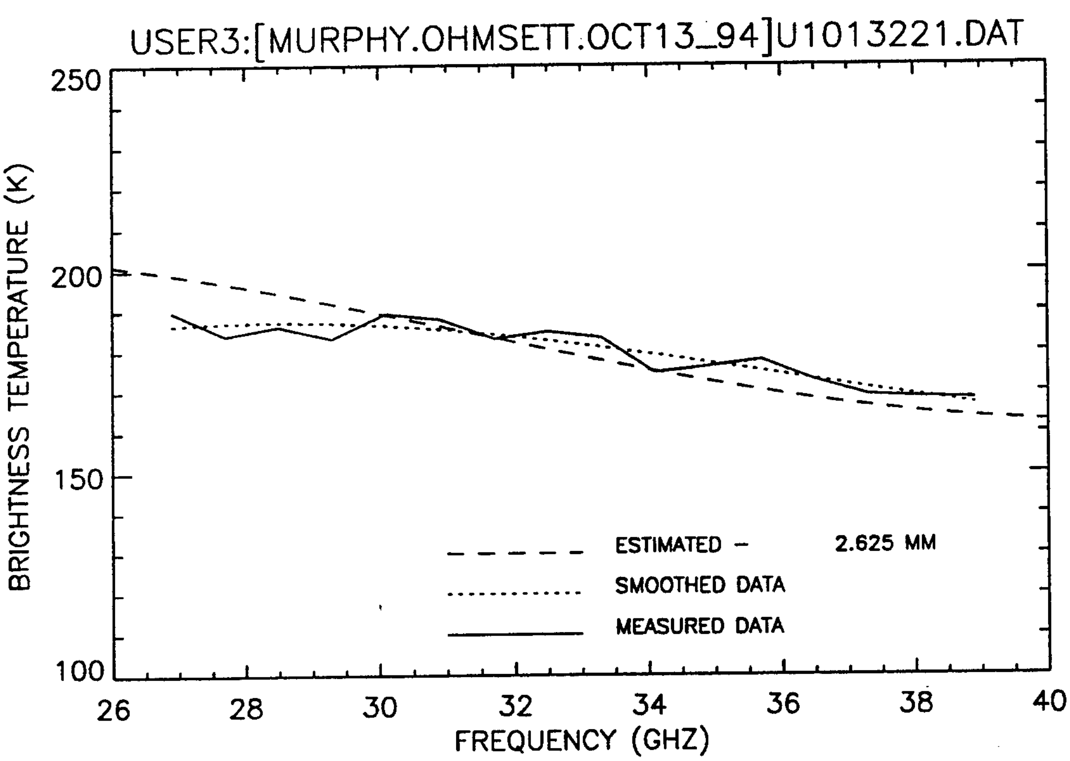

Figure D-15 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, Dyed Diesel, 13 October 1994, Pass 5

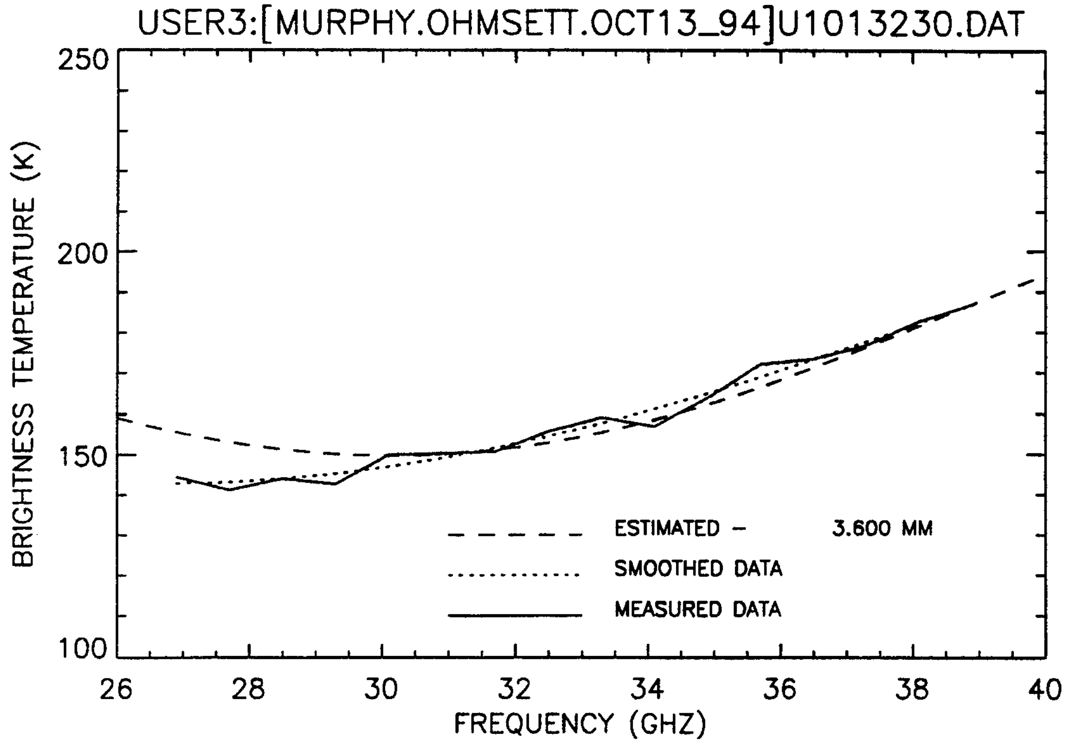

Figure D-16 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, Dyed Diesel, 13 October 1994, Pass 1

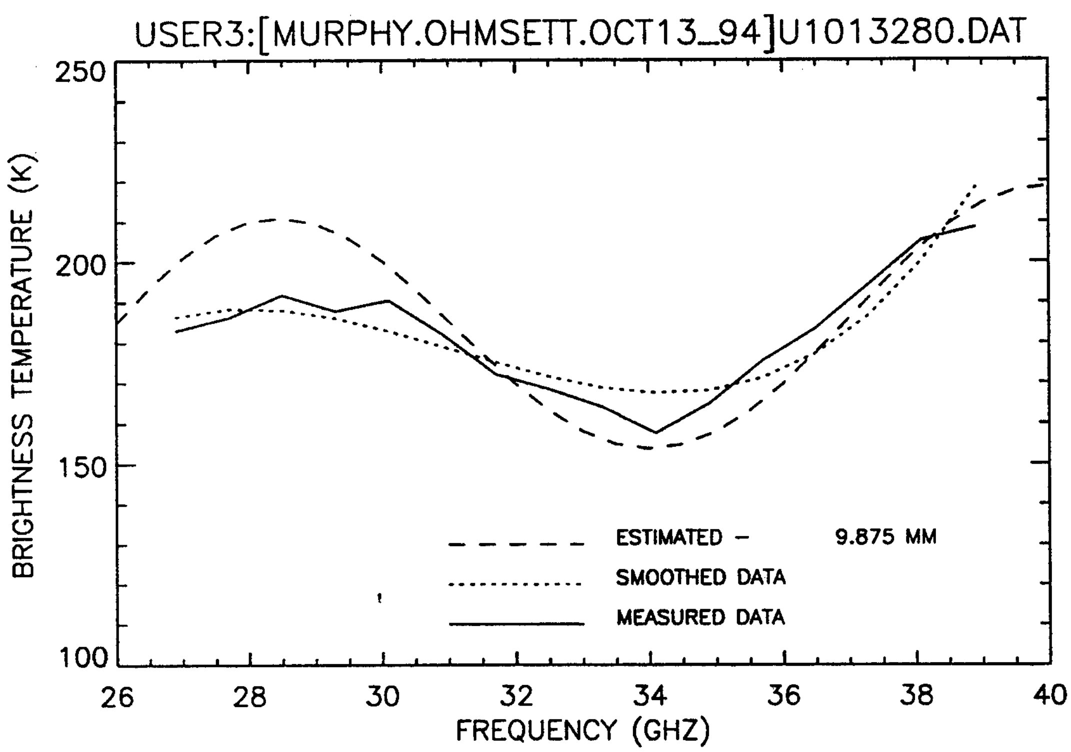

Figure D-17 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, Dyed Diesel, 13 October 1994, Pass 1

After the calm water measurements, the wave generator was set for wave condition 1. The wave conditions were allowed to reach steady-state (approximately 20 minutes) before data was collected on the oil target pools.

V101300A - This is the water reference chosen for this data set. This reference curve was actually collected before the start of the wave generator for direct comparison purposes with the water measurements under wave conditions.

V101300B - This curve is a good match to the algorithm estimate of 0.0 mm.

V101300C - This curve is a good match to the algorithm estimate of 0.0 mm.

V101300D - This curve is a good match to the algorithm estimate of 0.0 mm.

The following measurements were collected from the center of the 0.5 mm oil target pool.

V101305A - This curve is a good match to the algorithm estimate of 0.600 mm.

V101305B - This curve is a good match to the algorithm estimate of 0.400 mm.

V101305C - This curve is an excellent match to the algorithm estimate of 0.500 mm.

The following measurements were collected slightly north of the center from the 1.0 mm oil target pool in an area that visually appeared to be somewhat thicker than the oil in the southern part of the target pool.

V101310A - This curve is a poor match to the algorithm estimate of 2.375 mm. The curve seems to have the shape of a 1.9 mm estimate, however the overall T^B is too low. The result is inconclusive.

V101310B - This curve is a poor match to the algorithm estimate of 2.450 mm. The curve seems to have the shape of a 2.0 mm estimate, however the overall T^B is too low. The result is inconclusive.

V101310C - This curve is a poor match to the algorithm estimate of 0.850 mm. The curve is relatively flat and does not match any T^B curve well. The result is inconclusive.

The main bridge was moved 2 feet south to measure a slightly different target area within the same oil target pool. Visually, the oil did not appear quite as thick as the previous set of measurements.

V101310D - This curve is a good match to the algorithm estimate of 0.575 mm.
V101310E - This curve is an excellent match to the algorithm estimate of 0.725 mm.
V101310F - This curve is a good match to the algorithm estimate of 0.775 mm.

In this oil target, the oil appeared to have formed a wedge with the thinner part of the wedge west of center. The following measurements are from the thinner part of the wedge.

V101320A - This curve is a good-to-excellent match to the algorithm estimate of 0.325 mm.
V101320B - This curve is a good match to the algorithm estimate of 0.375 mm.
V101320C - This curve is a good match to the algorithm estimate of 0.450 mm.

The main bridge was moved somewhat south and the FSR aimed at the apparent thicker oil in the wedge east of center. The poor results from V101320D file are traced to the result of a bad V_{HOT} calibration.

V101320D - This curve is a poor match to the algorithm estimate of 2.900 mm. The curve does seem to exhibit a down slope which is a characteristic of the estimates from 2.5 - 3.0 mm; however, it is not a good match to any of the T^B curves in this range. The operator notes list a problem with the hot load calibration which would cause a bad measurement.
V101320E - This curve is a poor match to the algorithm estimate of 3.150 mm. The curve does seem to exhibit a somewhat flat shape with a low overall T^B which is a characteristic of the estimates from 3.0 - 3.5 mm; however, it is not a good match to any of the T^B curves in this range. The result is inconclusive.
V101320F - This curve is a poor-to-fair match to the algorithm estimate of 2.825 mm. The curve has a down slope that is a bit flatter than expected; however, the mean temperature of the curve seems to match well.

The main bridge was moved to the center of the 3.0 mm oil target for this set of measurements. The oil had no bubbles on the surface and appeared uniformly distributed across the target pool.

V101330A - This curve is a good match to the algorithm estimate of 3.300 mm.
V101330B - This curve is a good match to the algorithm estimate of 3.800 mm.
V101330C - This curve is a good match to the algorithm estimate of 0.450 mm.

The main bridge was moved 3 - 4 feet north to measure a different spot in the oil target pool.

V101330D - This curve is a good match to the algorithm estimate of 4.100 mm.
V101330E - This curve is a good match to the algorithm estimate of 4.125 mm.
V101330F - This curve is a good match to the algorithm estimate of 4.075 mm.

The main bridge was moved to the center of the 8.0 mm pool. Bubbles were observed on the surface of the oil target pool. In previous instances, when bubbles were present in the measurement, the T^B response was flat, but unlike some emulsions, the overall (mean) T^B response is in the range of radiometric temperatures expected for oil.

V101380A - This curve is a poor match to the algorithm estimate of 0.825 mm. The curve is relatively flat and does not exhibit the sinusoidal trait of on 8.0 mm estimate. The result is inconclusive.

V101380B - This curve is a poor match to the algorithm estimate of 0.850 mm. The overall T^B seems too low to support the algorithm estimate, but the shape seems to match reasonably well. The curve is relatively flat and does not exhibit the sinusoidal trait of on 8.0 mm estimate. The result is inconclusive.

V101380C - This curve is a poor match to the algorithm estimate of 0.900 mm. The overall T^B seems too low to support the algorithm estimate, but the shape seems to match reasonably well. The curve is relatively flat and does not exhibit the sinusoidal trait of on 8.0 mm estimate. The result is inconclusive.

The main bridge was moved south 3 - 4 feet to measure from a different part of the oil target pool. Again, bubbles are present on the surface of the oil.

V101380D - This curve is a poor match to the algorithm estimate of 0.875 mm. The curve is relatively flat and does not exhibit the sinusoidal trait of on 8.0 mm estimate. The result is inconclusive.

V101380E - This curve is a poor match to the algorithm estimate of 0.925 mm. The curve is relatively flat and does not exhibit the sinusoidal trait of on 8.0 mm estimate. The result is inconclusive.

These measurements seem consistent, but do not match the theoretical predictions. The only visual effect noted in the on-site log and observed in the video is the presence of bubbles on the surface of the oil. Another possibility is that the oil thickness is varying in the waves during the FSR measurement interval (12 seconds), causing some type of time averaging effect.

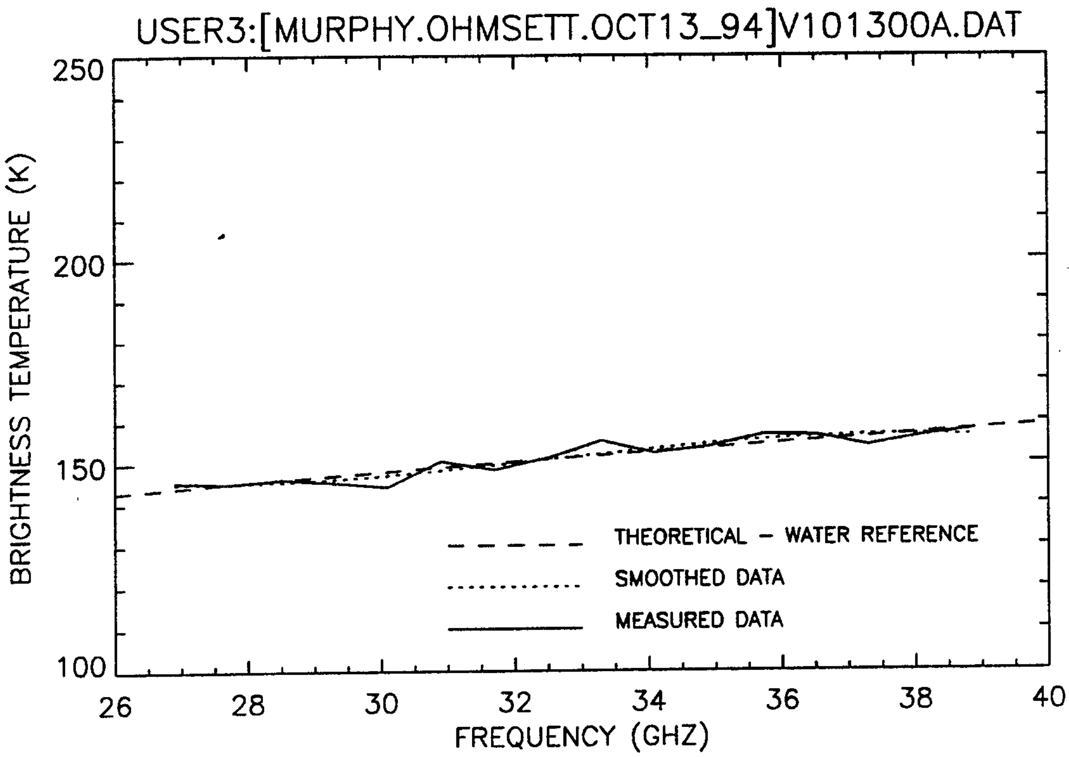

Figure D-18 T^B Versus Frequency Plot for Background Water, Calm Water, 13 October 1994, Pass 1

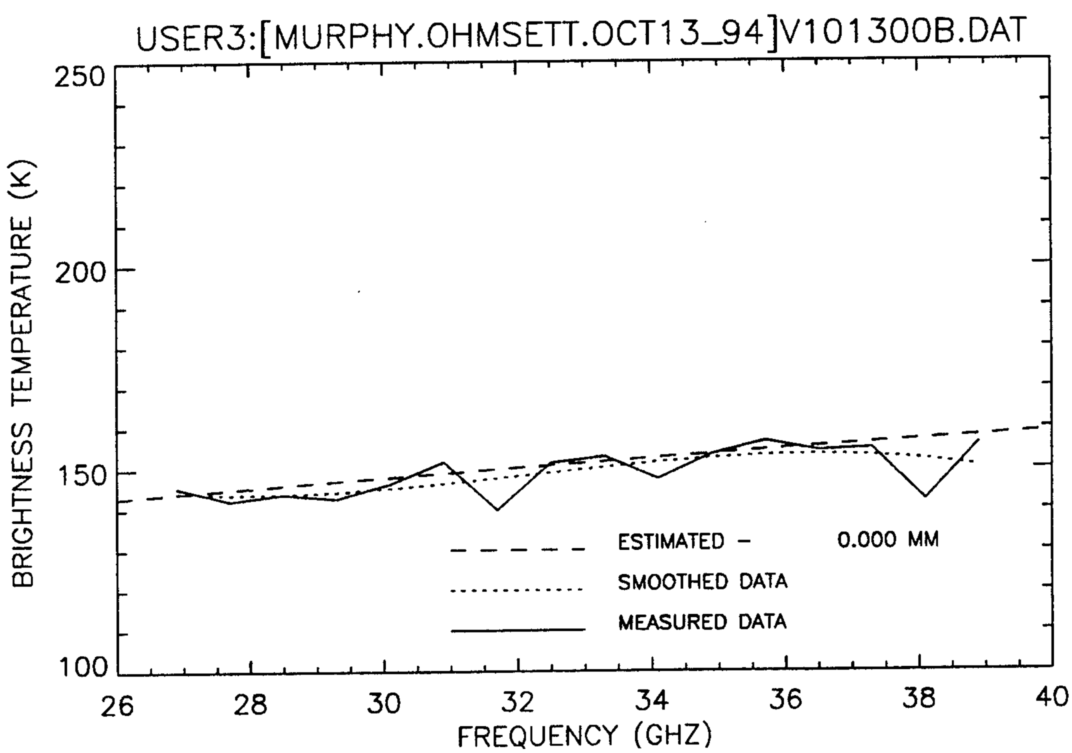

Figure D-19 T^B Versus Frequency Plot for Background Water, Wave Condition 1, 13 October 1994, Pass 2

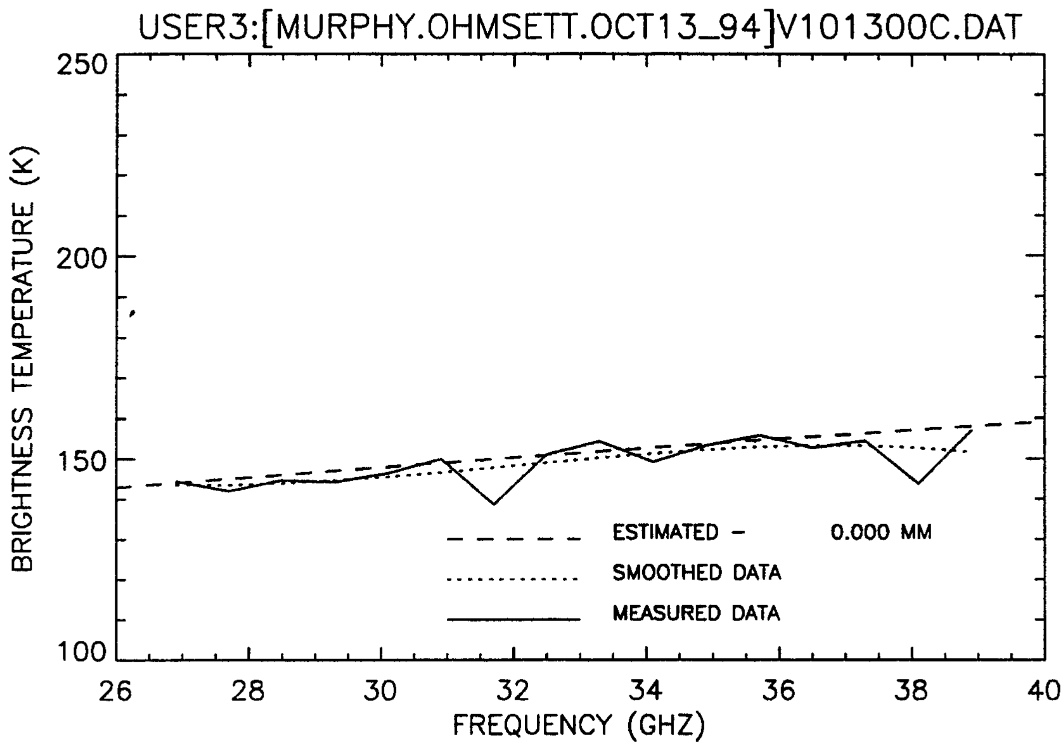

Figure D-20 T^B Versus Frequency Plot for Background Water, Wave Condition 1, 13 October 1994, Pass 3

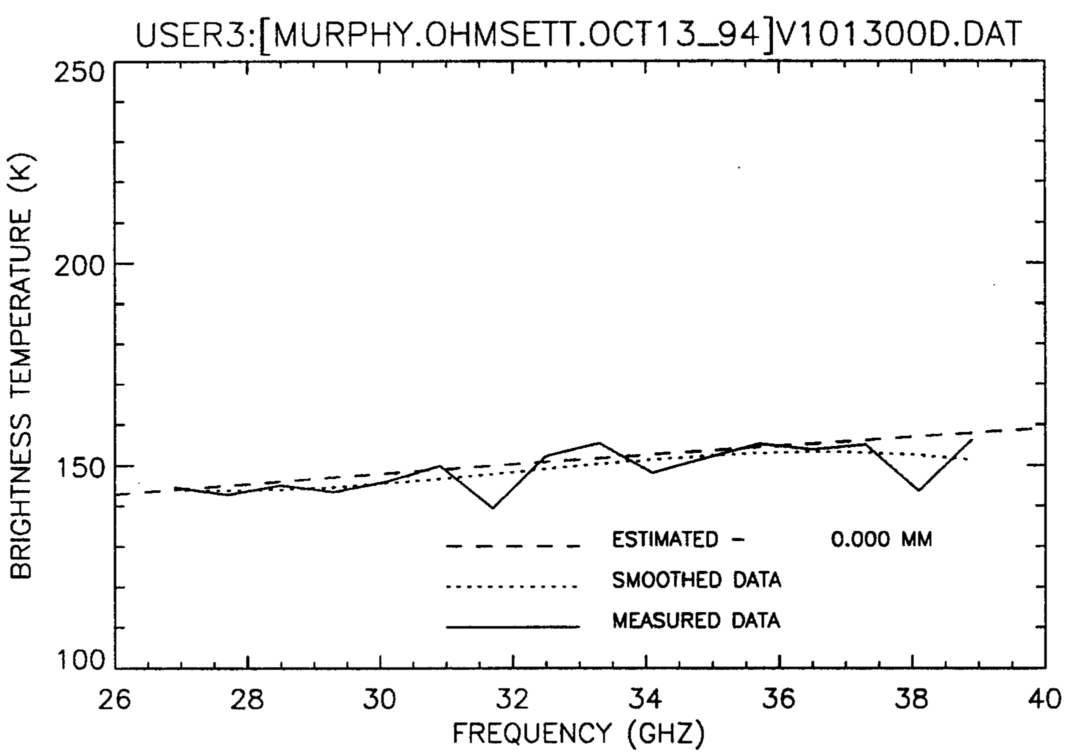

Figure D-21 T^B Versus Frequency Plot for Background Water, Wave Condition 1, 13 October 1994, Pass 4

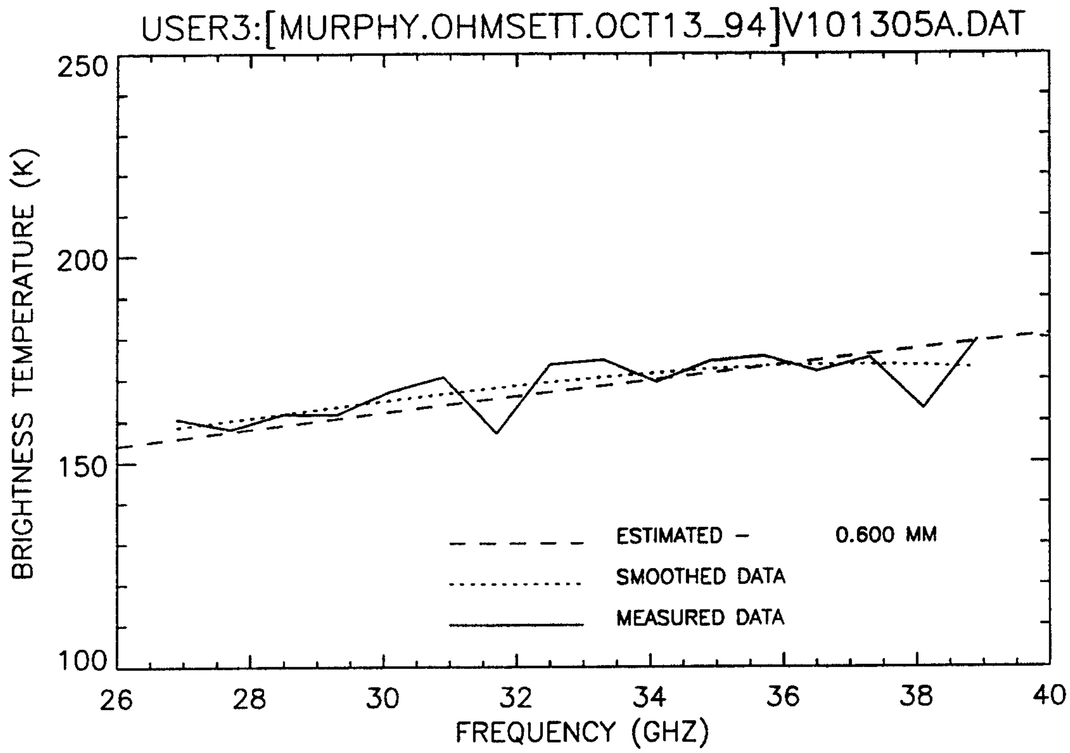

Figure D-22 T^B Versus Frequency Plot for 0.5 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 1

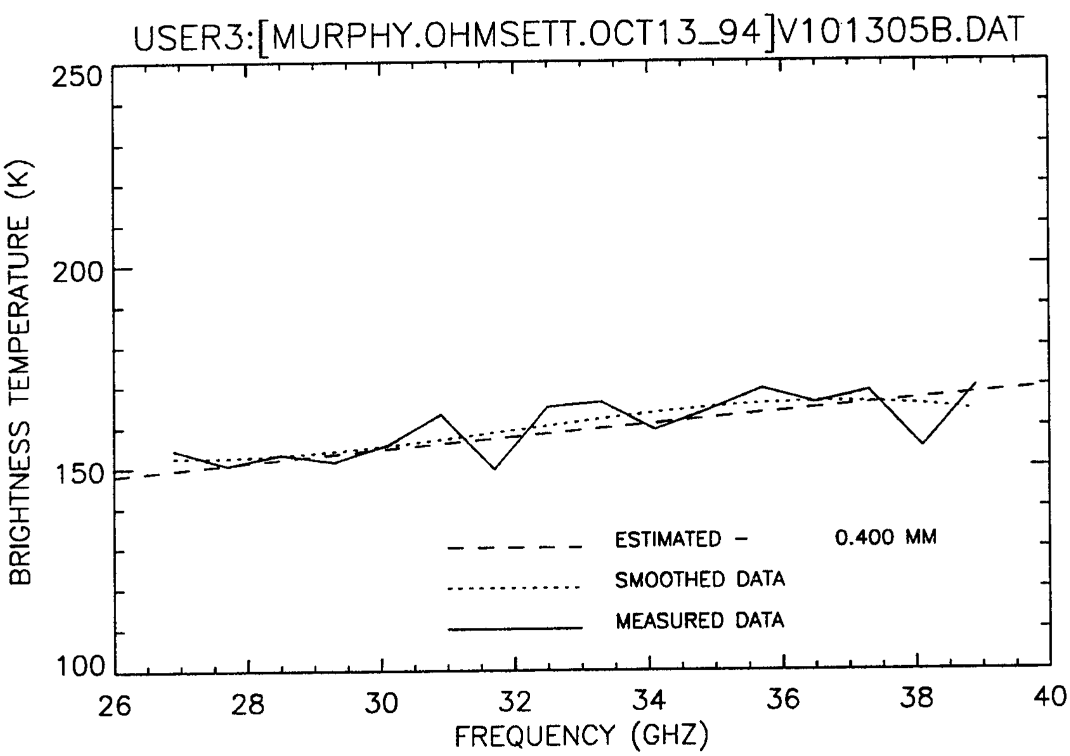

Figure D-23 T^B Versus Frequency Plot for 0.5 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 2

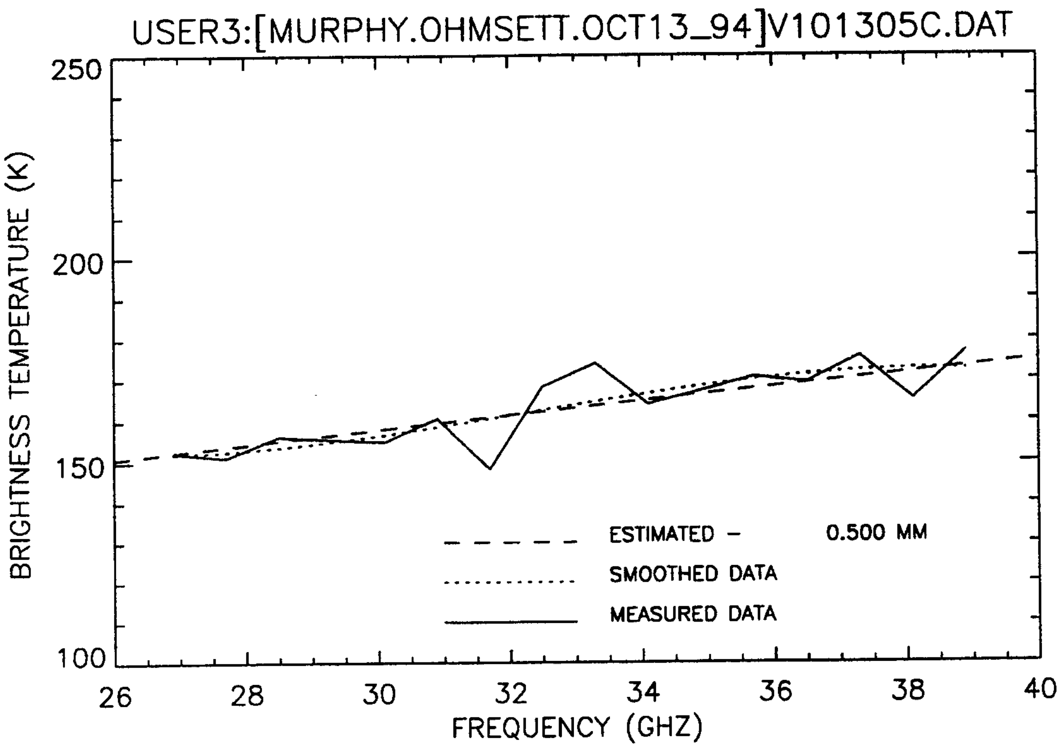

Figure D-24 T^B Versus Frequency Plot for 0.5 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 3

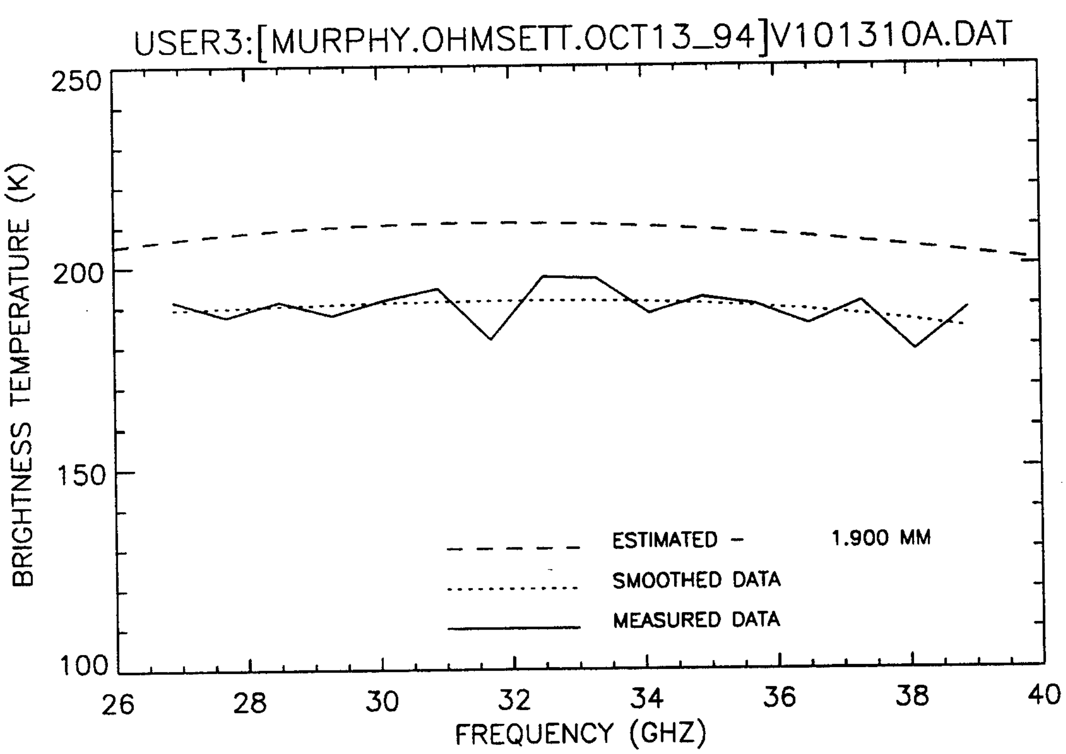

Figure D-25 T^B Versus Frequency Plot for 1.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 1

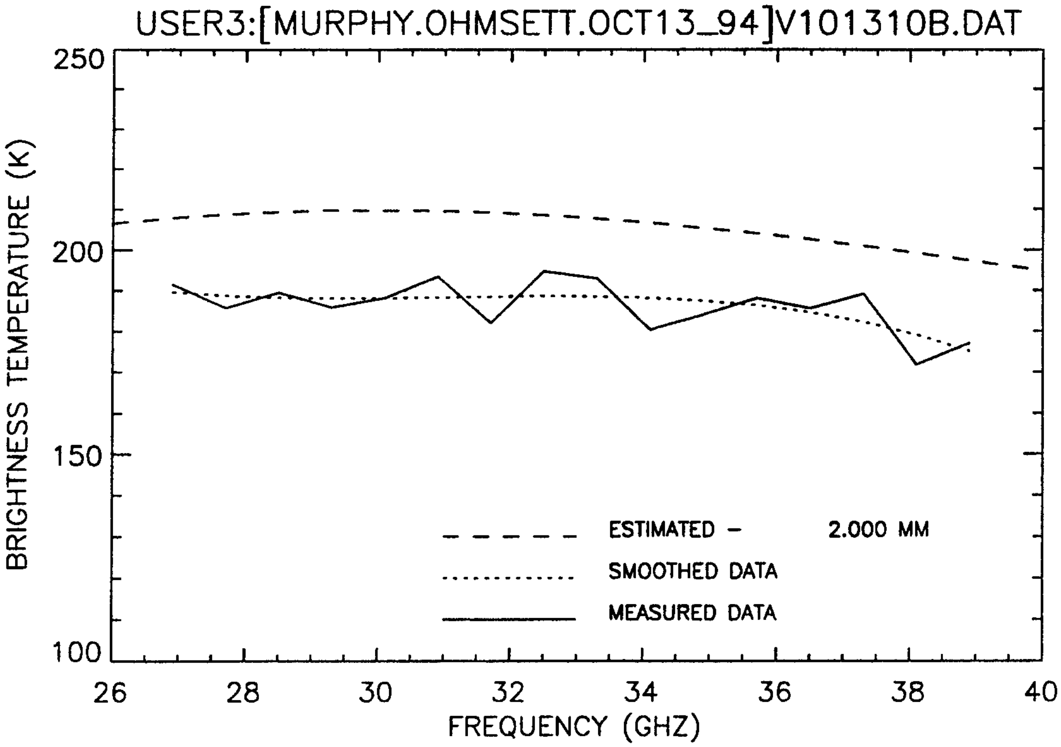

Figure D-26 T^B Versus Frequency Plot for 1.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 2

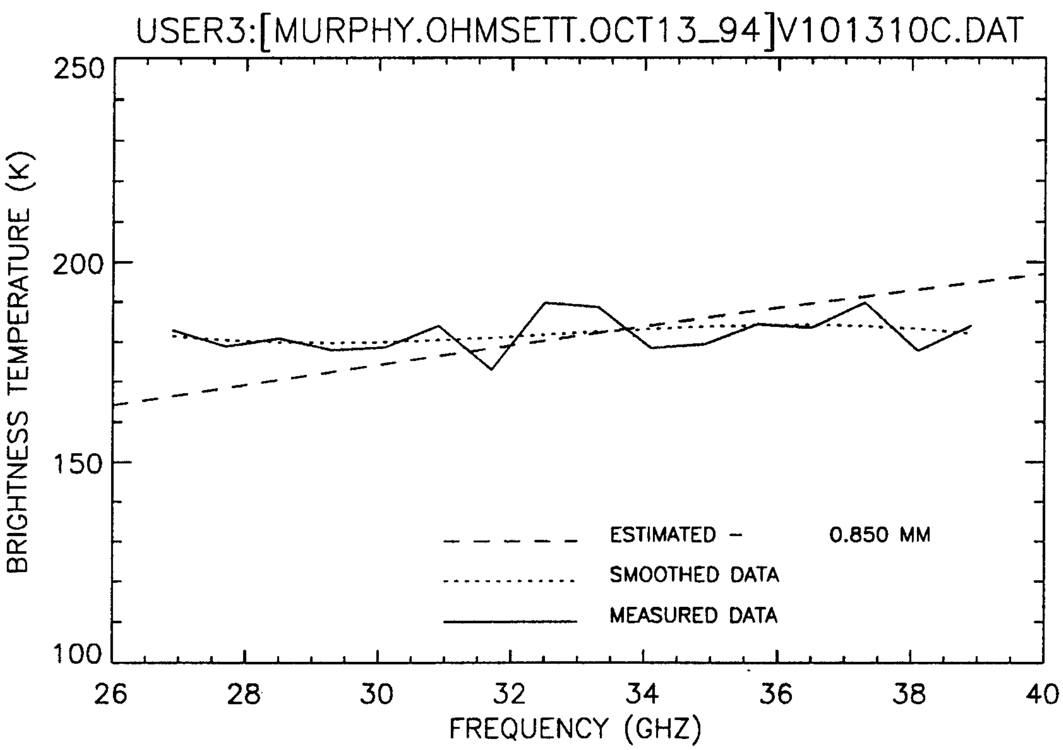

Figure D-27 T^B Versus Frequency Plot for 1.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 3

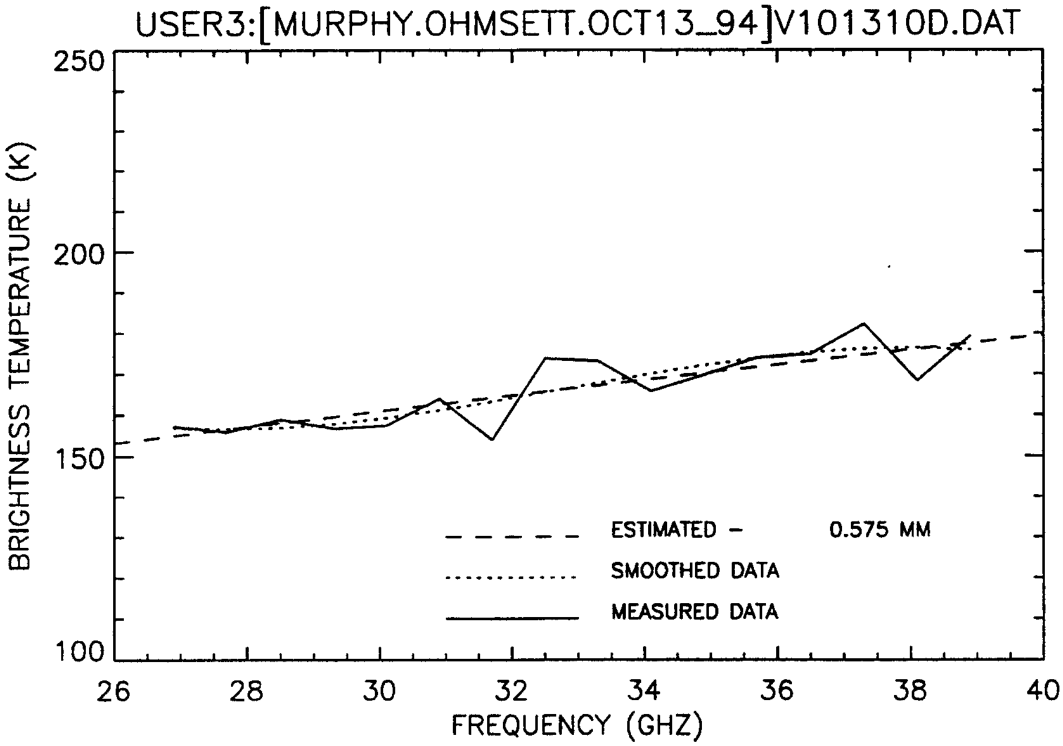

Figure D-28 T^B Versus Frequency Plot for 1.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 4

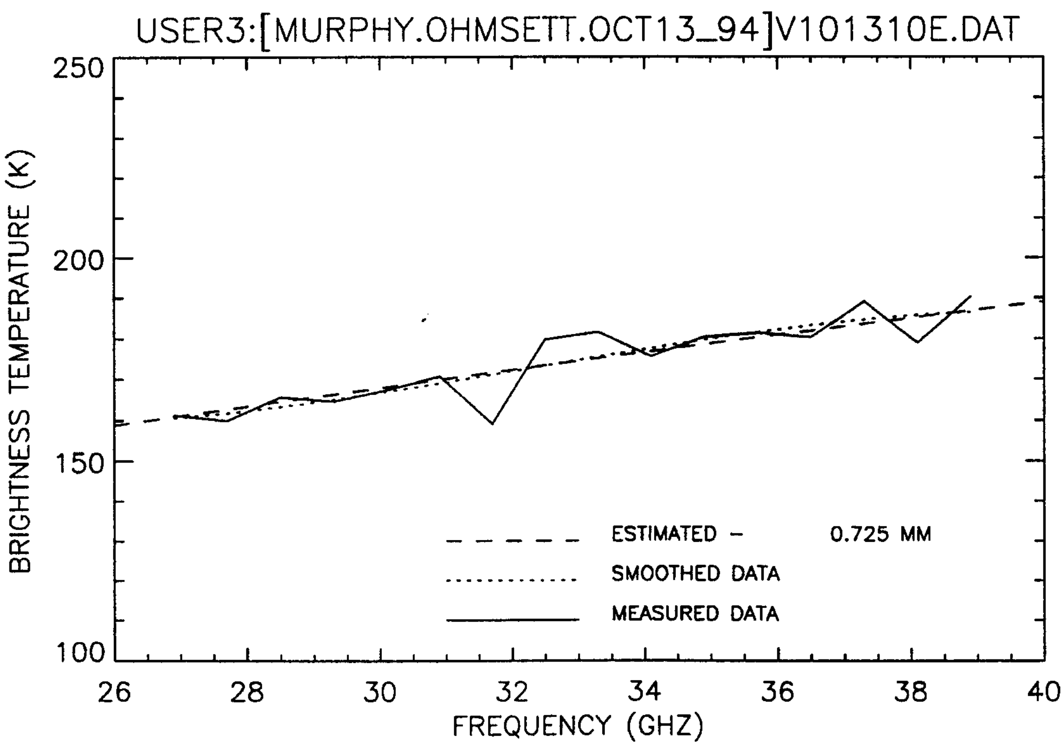

Figure D-29 T^B Versus Frequency Plot for 1.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 5

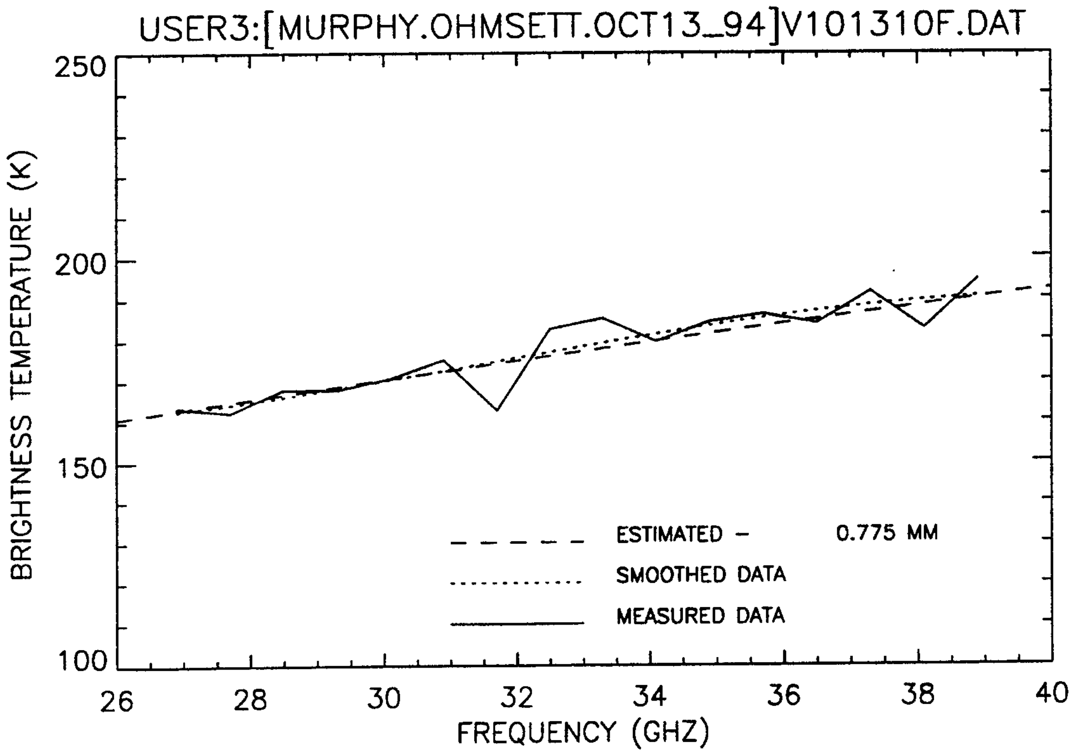

Figure D-30 T^B Versus Frequency Plot for 1.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 6

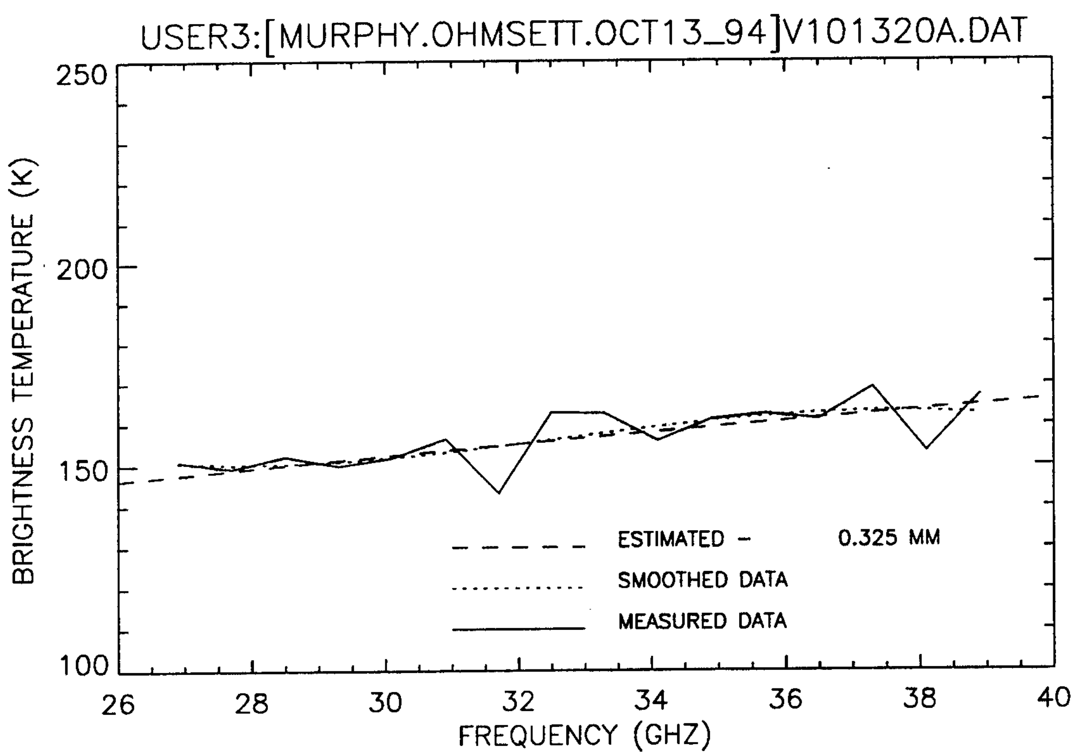

Figure D-31 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 1

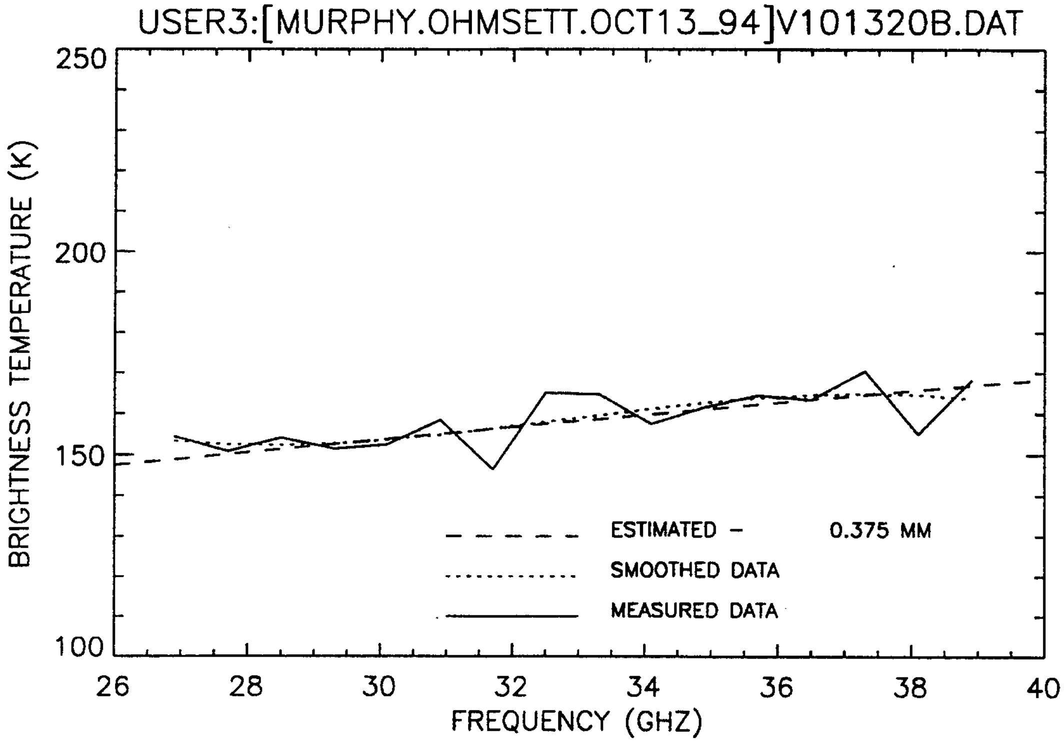

Figure D-32 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 2

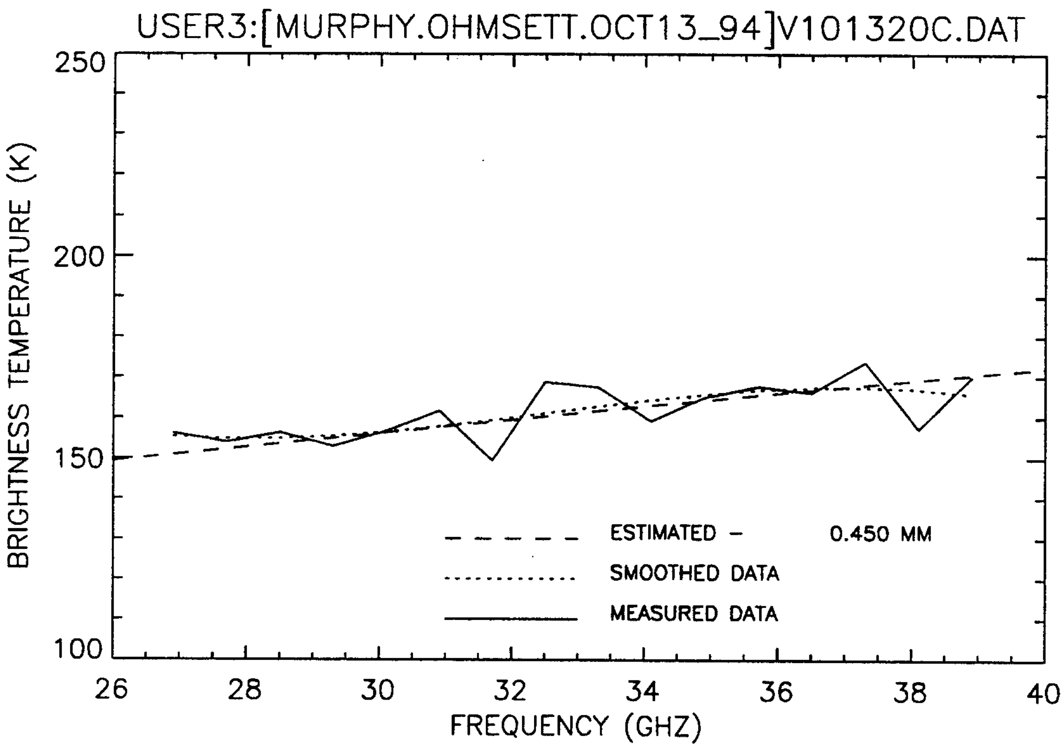

Figure D-33 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 3

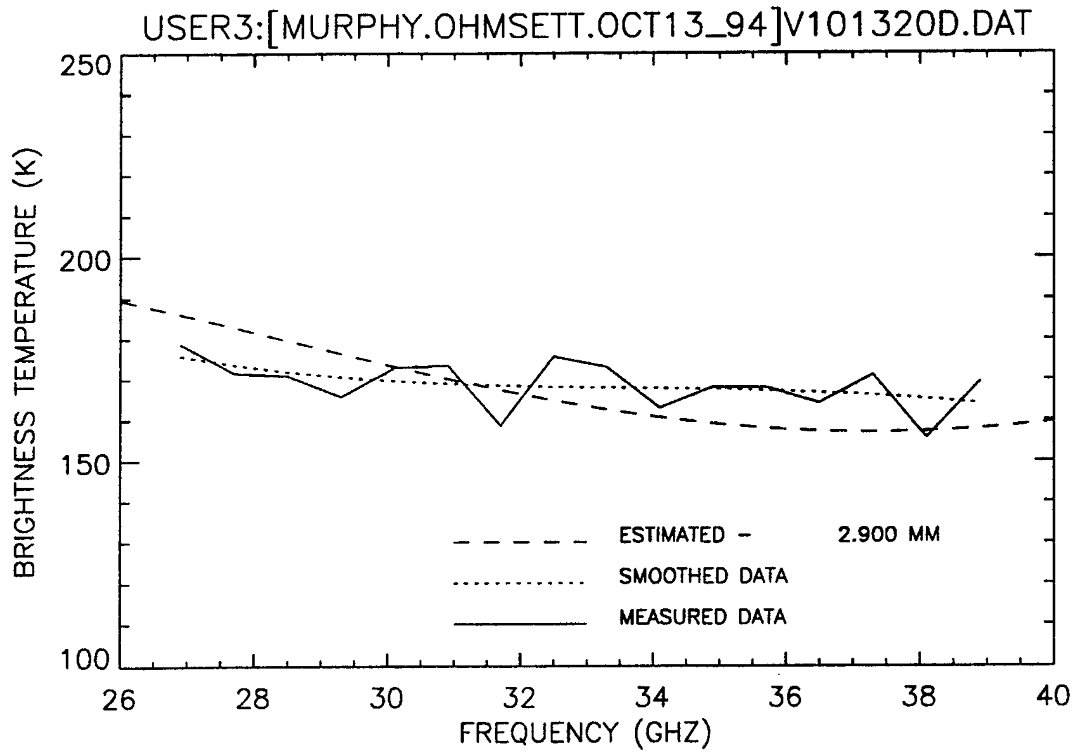

Figure D-34 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 4

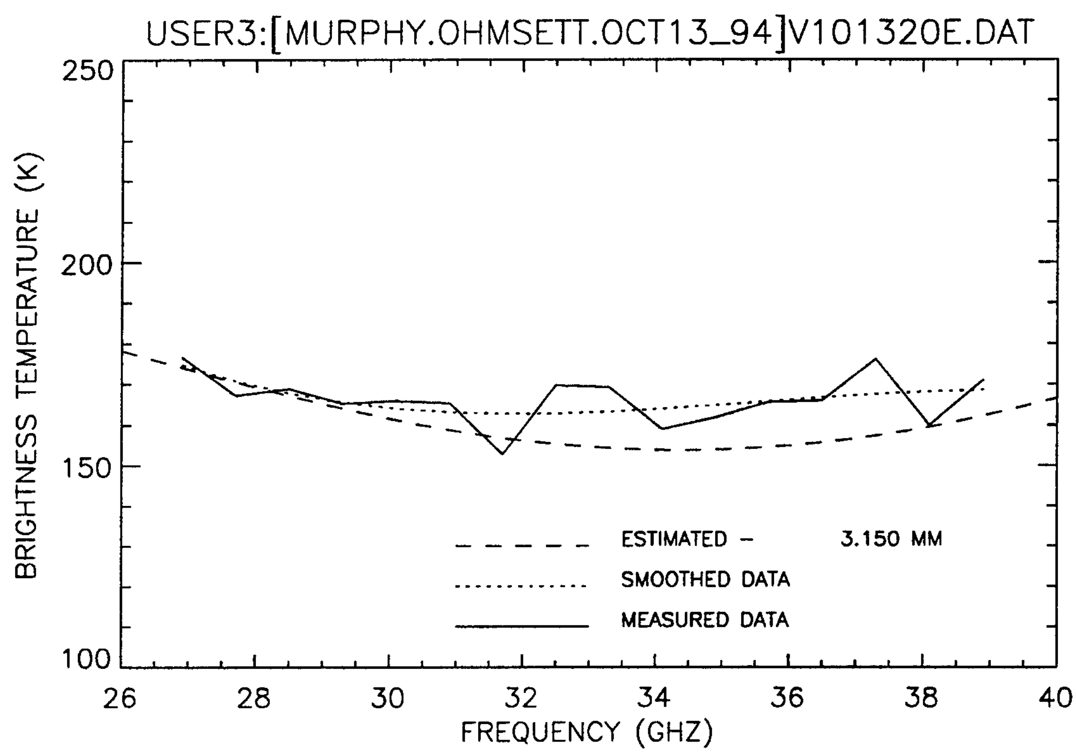

Figure D-35 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 5

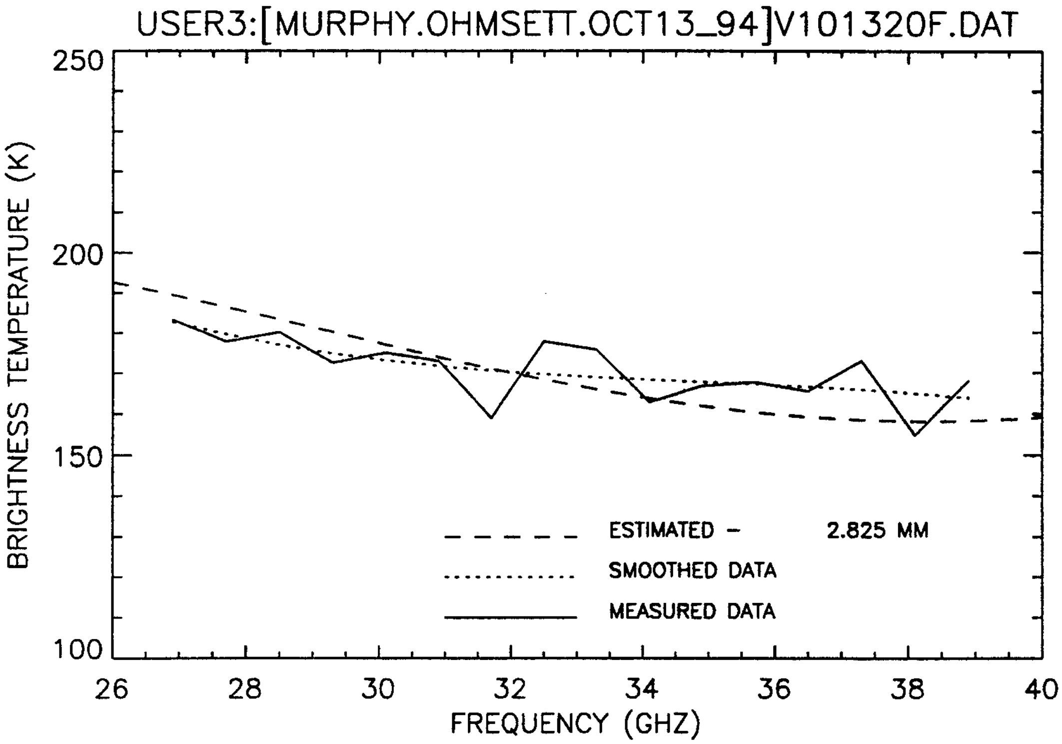

Figure D-36 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 6

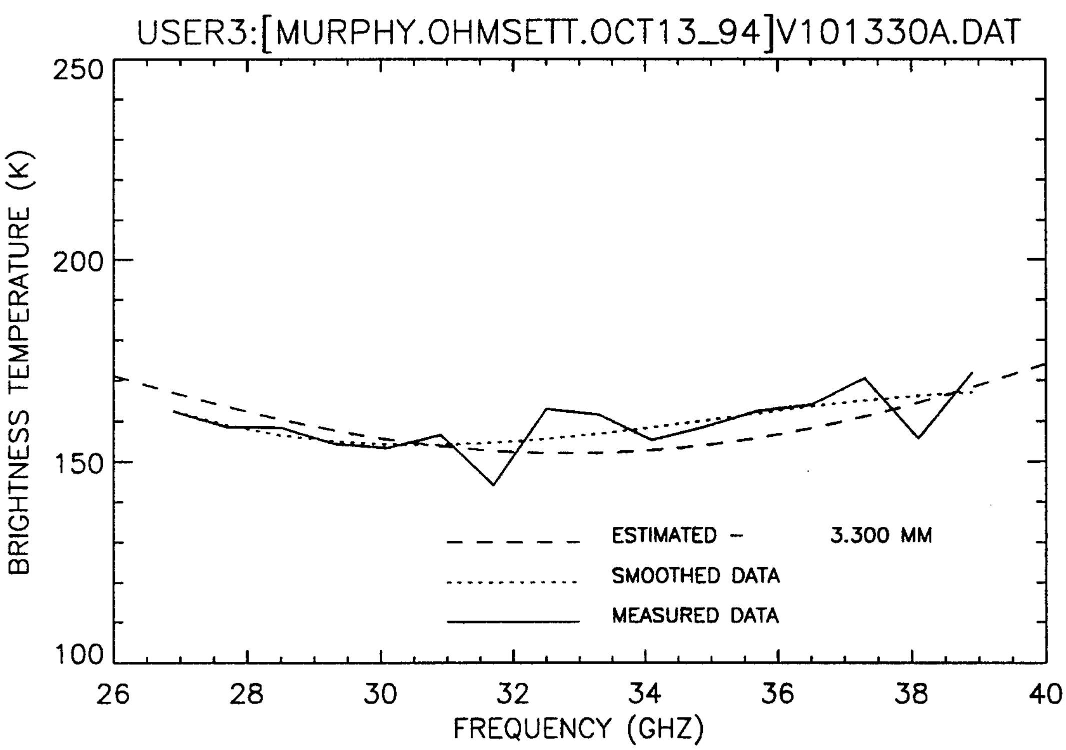

Figure D-37 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 1

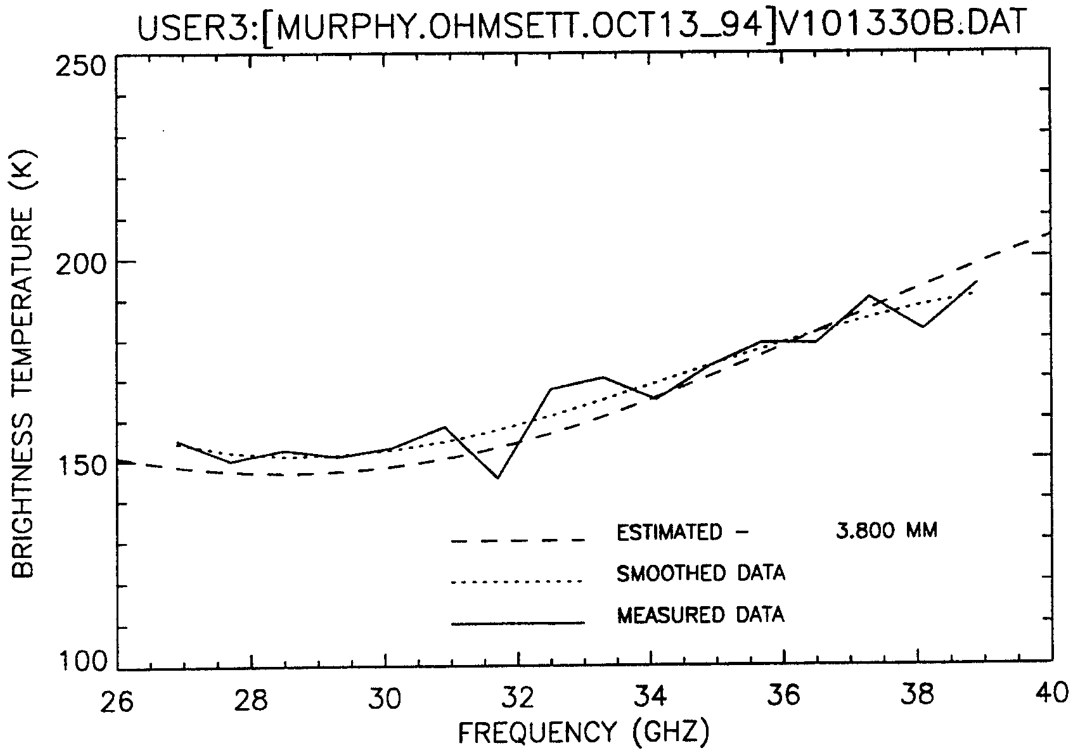

Figure D-38 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 2

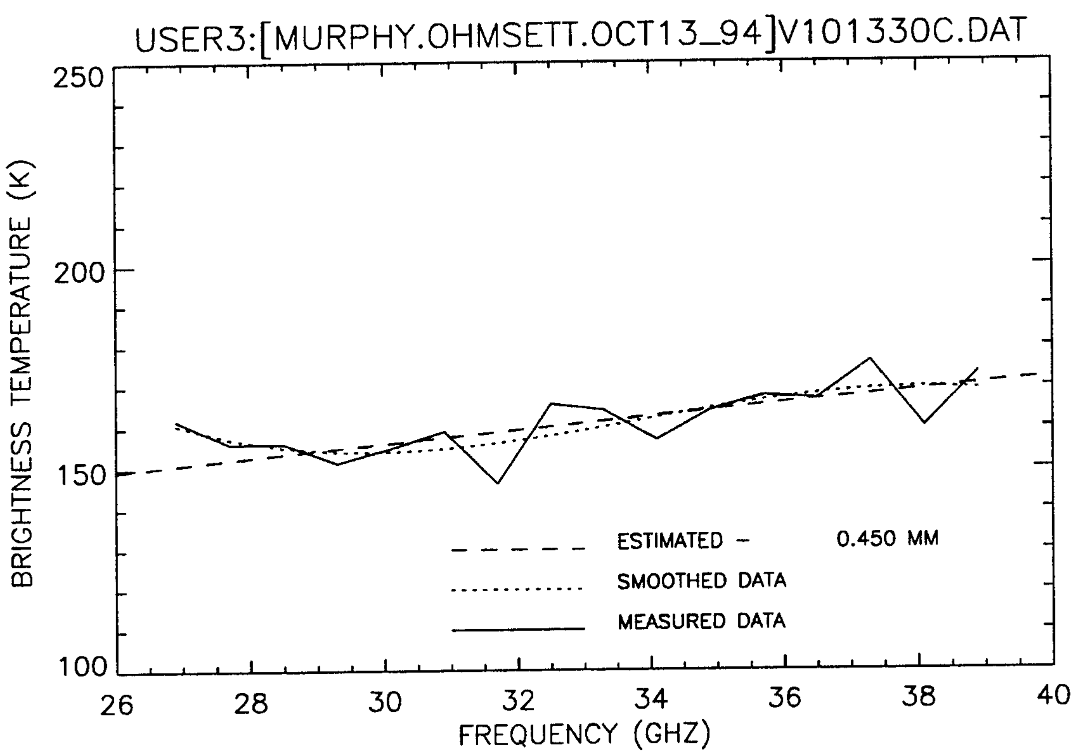

Figure D-39 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 3

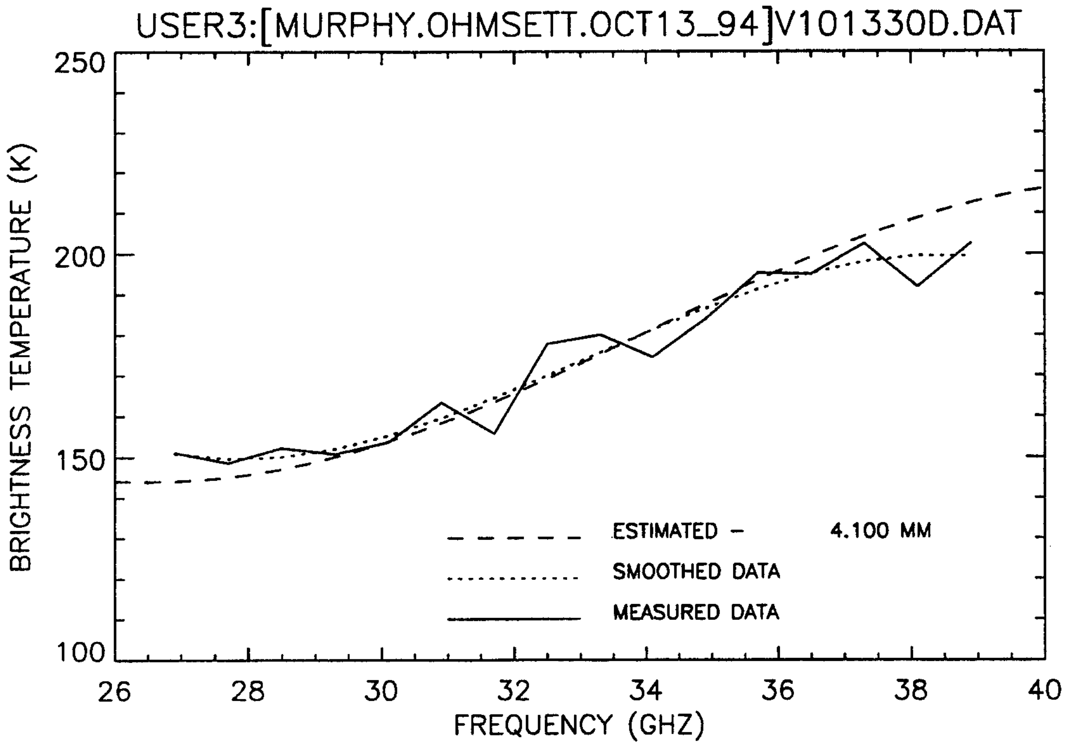

Figure D-40 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 4

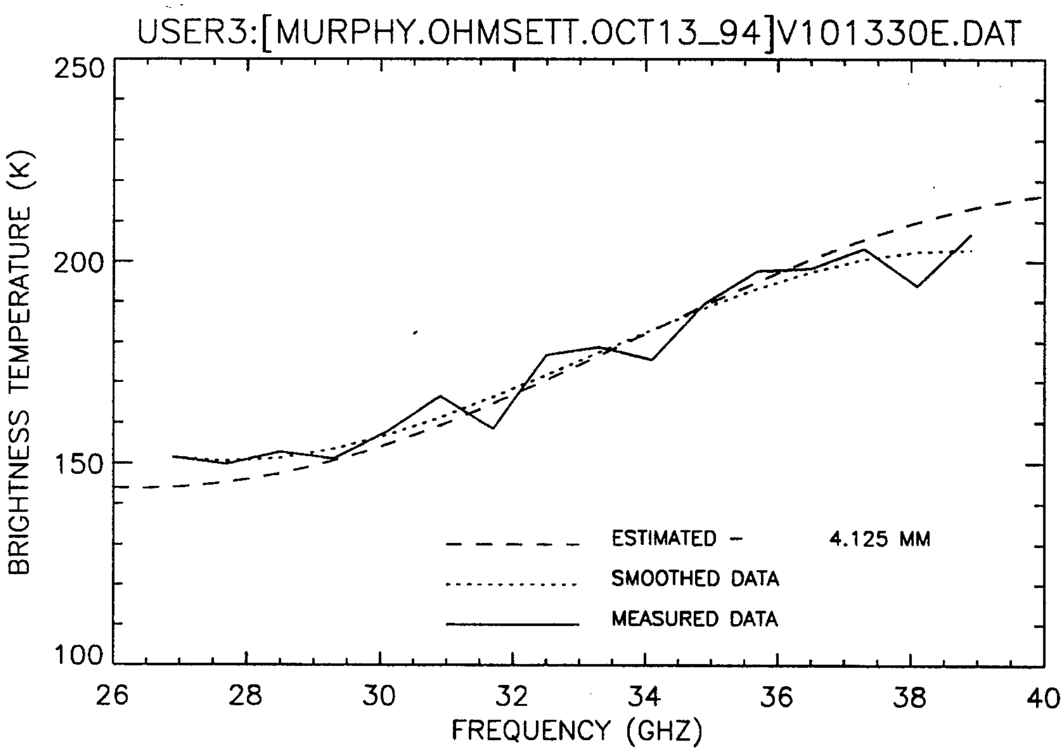

Figure D-41 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 5

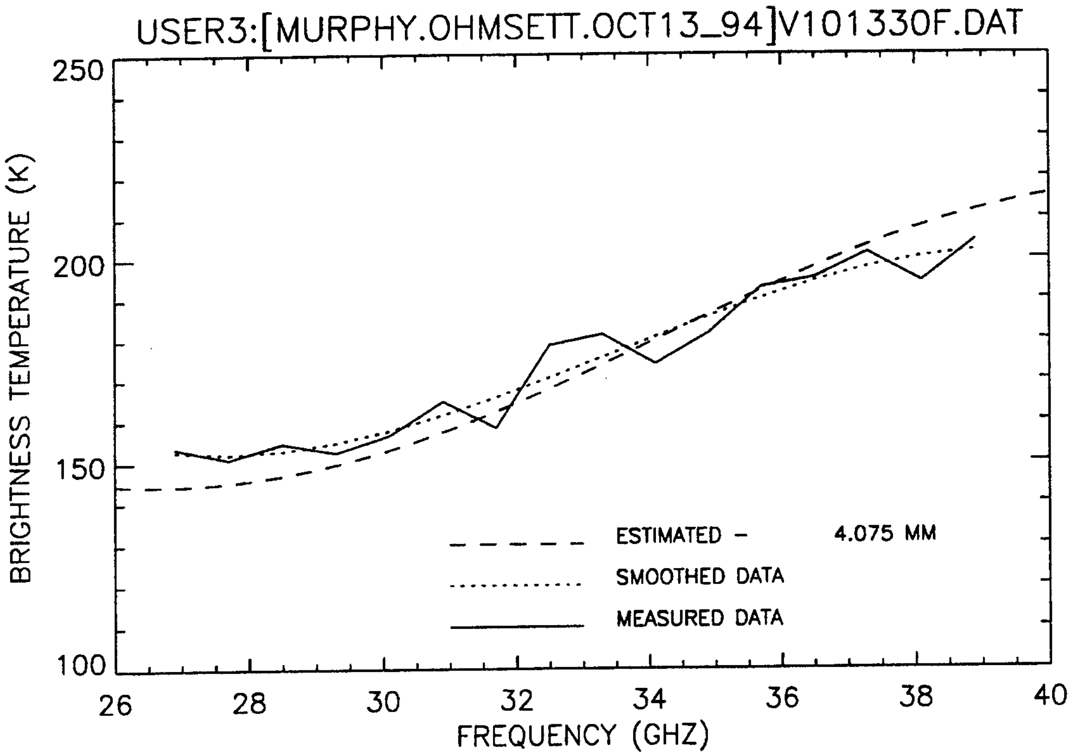

Figure D-42 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 6

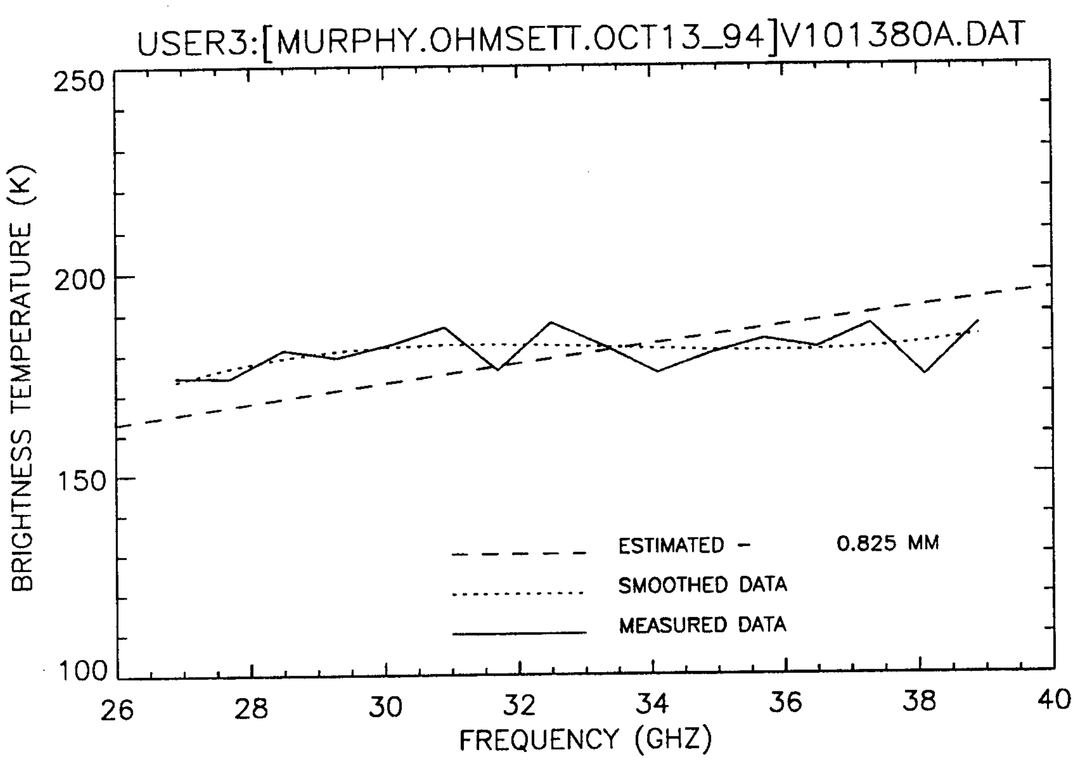

Figure D-43 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 1

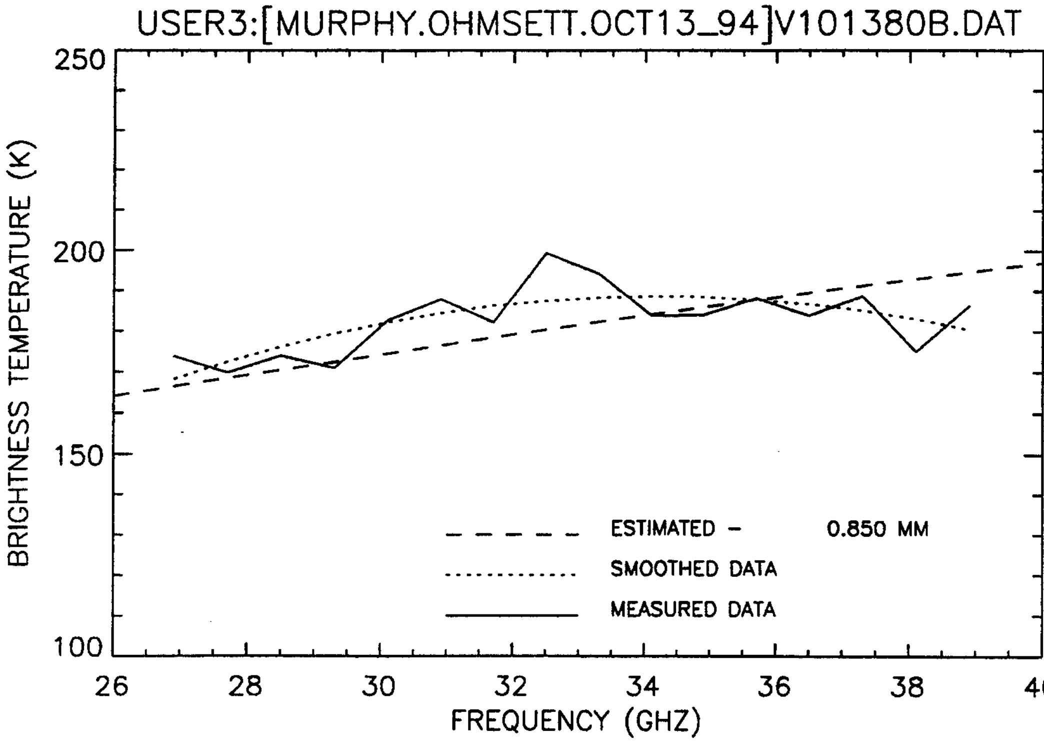

Figure D-44 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 2

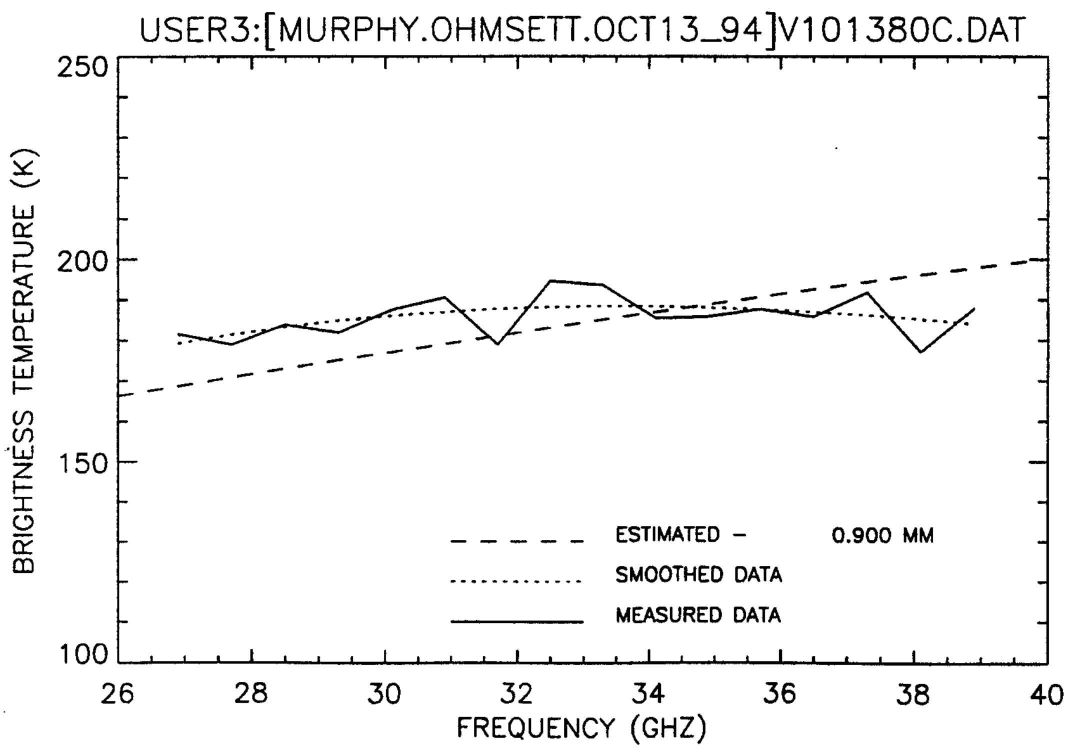

Figure D-45 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 3

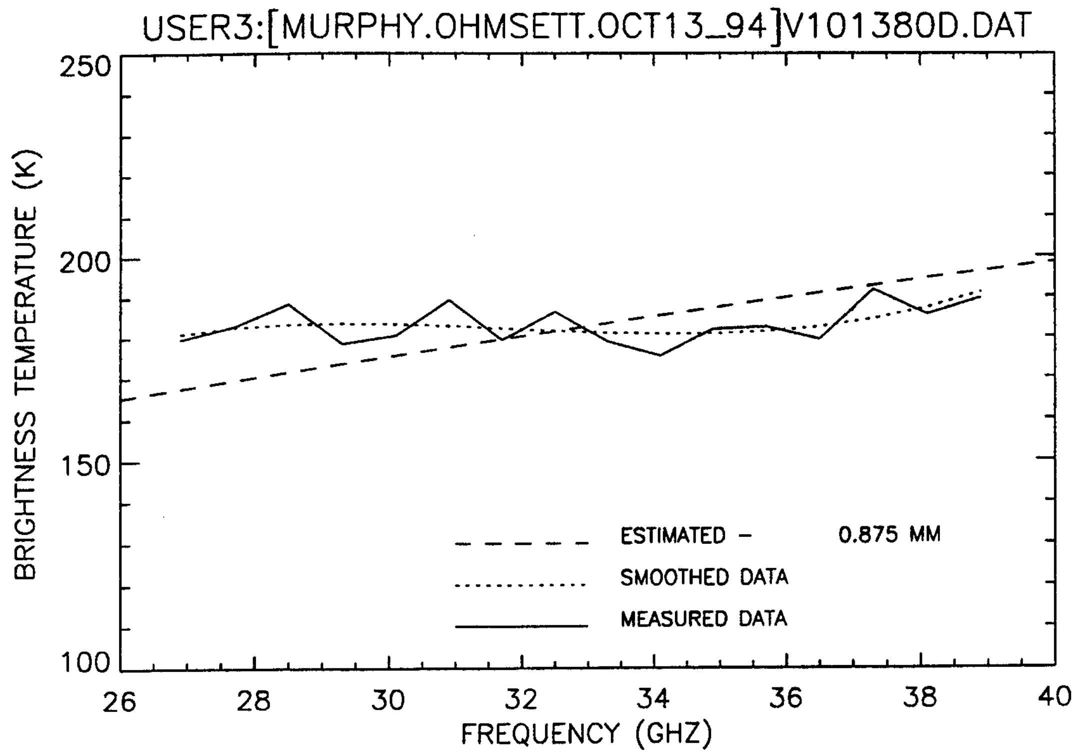

Figure D-46 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 4

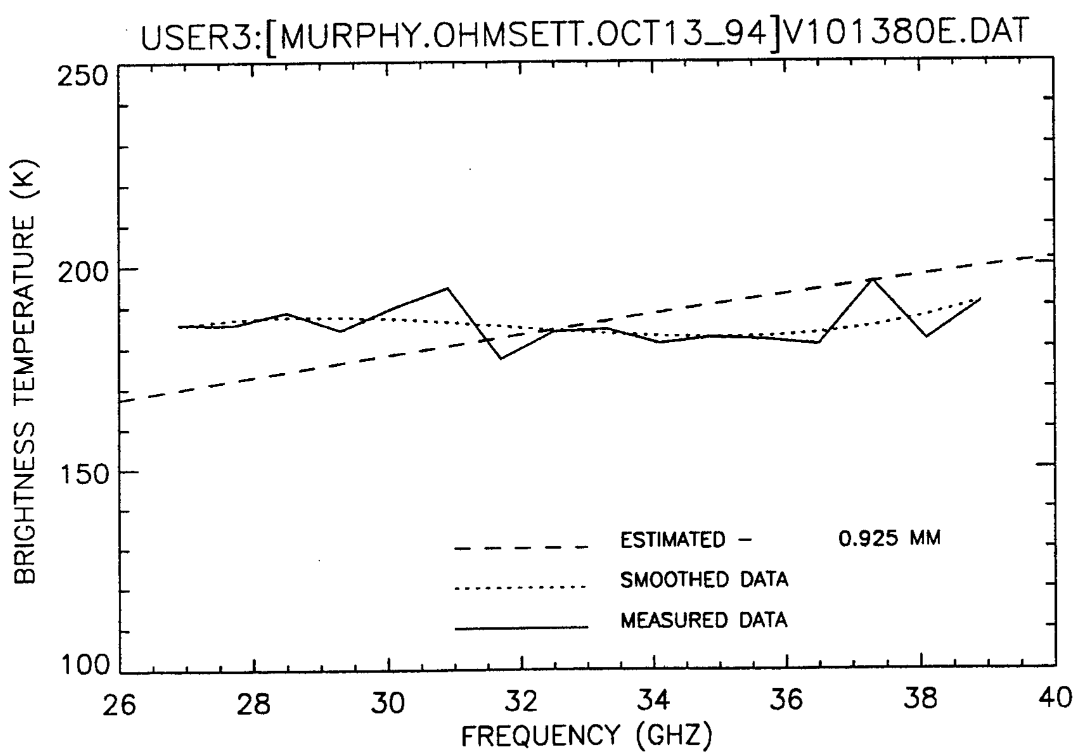

Figure D-47 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Wave Condition 1, 13 October 1994, Pass 5

After the wave condition 1 measurements were complete, the wave generator was reset to provide wave condition 2. Data collection commenced after the waves had reached a steady state condition (approximately 20 minutes). With the increased wave state, more noise seems to appear in the measurements; the increased noise level may be due to sun glinting effects.

W101300A - This curve was chosen as the background water reference for this set of measurements. It is believed that the large jumps in the measured data are due to sun glinting effects from the wave surfaces.

W101300B - This curve is a fair-to-good match to the algorithm estimate of 0.000 mm.

W101300C - This curve is a poor match to the algorithm estimate of 0.000 mm based on the W101300A reference. The overall T^B seems a bit lower than the first water estimate, but the shape matches the expected water response.

The main bridge was positioned for the FSR to make measurements from the center of the oil target pool.

W101305A - This curve is a fair match to the algorithm estimate of 0.300 mm.

W101305B - This curve is a poor match to the algorithm estimate of 0.450 mm. There appears to be a sinusoidal variation in the data. This variation could be the result of a partial beam fill effect of a thicker oil film, or more likely, an artifact of the "spikiness" of the data. The red dye in the oil is too pale to get an indication of any thickness variations in the target pool. The result is inconclusive.

W101305C - This curve is a fair match to the algorithm estimate of 0.400 mm, although some slight sinusoidal variation is seen.

The main bridge was moved two feet south and the FSR positioned to measure from the west side of the oil target. There were some bubbles present on the surface of the oil that was in the antenna footprint. The results are somewhat surprising, since the presence of bubbles usually creates a virtually flat T^B response.

W101305D - This curve is a good match to the algorithm estimate of 1.225 mm.

W101305E - This curve is a fair match to the algorithm estimate of 1.050 mm.
W101305F - This curve is a good match to the algorithm estimate of 0.775 mm.

The main bridge was moved over the 1.0 mm oil target pool with the FSR set to measure oil in the center of the pool. The east side of the oil target appears to be somewhat thicker than the west side. Some bubbles are beginning to form around the edges of the oil target due to the effect of the containment booms.

W101310A - This curve is a poor match to the algorithm estimate of 2.525 mm. Although the shape seems to match a 1.900 mm estimate (plotted) well, the overall T^B is too low. The result is inconclusive.
W101310B - This curve is a poor match to the algorithm estimate of 2.575 mm. Although the shape seems to match a 1.900 mm estimate (plotted) well, the overall T^B is too low. The result is inconclusive.
W101310C - This curve is a poor match to the algorithm estimate of 0.850 mm. The measured curve is somewhat flat, and does not match any theoretical T^B predictions well. The result is inconclusive.

The main bridge was moved to the 2.0 mm oil target pool. The oil here in the center of the pool appeared to be thinner than the oil near the east side. Some bubbles are beginning to form around the edges of the oil target due to the effect of the containment booms, but these bubbles do not appear to be in the antenna footprint during measurements. There were no other significant features observed.

W101320A - This curve is a poor match to the algorithm estimate of 1.000 mm. The measured curve is somewhat flat, and does not match any theoretical T^B predictions well. The result is inconclusive.
W101320B - This curve is a poor match to the algorithm estimate of 0.800 mm. The measured curve is somewhat flat, and does not match any theoretical T^B predictions well. The result is inconclusive.
W101320C - This curve is a fair match to the algorithm estimate of 0.775 mm. The tails do not seem to match well, but the slope characteristic of the measured data from 31 GHz to 36 GHz seems to match the estimate well.

The FSR was re-positioned to measure the east side of the oil target where the oil appeared visually thicker.

W101320D - This curve is a fair match to the algorithm estimate of 0.800 mm. The tails do not seem to match well, but the slope characteristic of the measured data from 30 GHz to 37 GHz seems to match the estimate well.

W101320E - This curve is a poor match to the algorithm estimate of 2.175 mm. The overall T^B is close to a 2.0 mm estimate and the shape of the curve seems to match reasonably well.

W101320F - This curve is a good match to the algorithm estimate of 1.050 mm.

The poor results seen here and in the following measurements may be due to the oil thickness varying in the waves during the FSR measurement interval (12 seconds), causing some type of time averaging effect.

The main bridge was moved to the 3.0 mm oil target pool. The first two measurements were collected in an area that appeared to have thick oil pools.

W101330A - This curve is a good match to the algorithm estimate of 1.025 mm.

W101330B - This curve is a poor match to the algorithm estimate of 1.000 mm. The measured curve seems to have a slight curvature which resembles a 4.6 mm estimate (plotted). The result is inconclusive.

The FSR was re-positioned to measure the center of the oil target.

W101330C - This curve is a good match to the algorithm estimate of 1.000 mm.

W101330D - This curve is a fair match to the algorithm estimate of 0.950 mm.

W101330E - This curve is a fair-to-good match to the algorithm estimate of 0.850 mm.

W101330F - This curve is a poor match to the algorithm estimate of 2.300 mm. The slope is flat and the curve does not match any estimated T^B predictions well. The result is inconclusive.

W101330G - This curve is a poor match to the algorithm estimate of 1.175 mm. The measured curve seems to have a slight curvature which resembles a 1.7 mm estimate although the overall T^B is too low. The result is inconclusive.

The main bridge was moved to the center of the 8.0 mm oil target pool. Bubbles were present on the surface of the oil.

W101380A - This curve is a poor match to the algorithm estimate of 1.425 mm. The slope is somewhat flat but the peaks of the measured data curve do tend to follow the estimated curve. The curve does not exhibit any of the sinusoidal variation expected by an 8.0 mm measurement.

W101380B - This curve is a fair-to-good match to the algorithm estimate of 1.500 mm. The curve does not exhibit any of the sinusoidal variation expected for an 8.0 mm measurement.

W101380C - This curve is a poor match to the algorithm estimate of 1.650 mm. The high T^B indicates an emulsion. The curve does not exhibit the sinusoidal variation expected for an 8.0 mm measurement.

W101380D - This curve is a poor match to the algorithm estimate of 1.650 mm. The high T^B indicates an emulsion. The curve does not exhibit the sinusoidal variation expected for an 8.0 mm measurement.

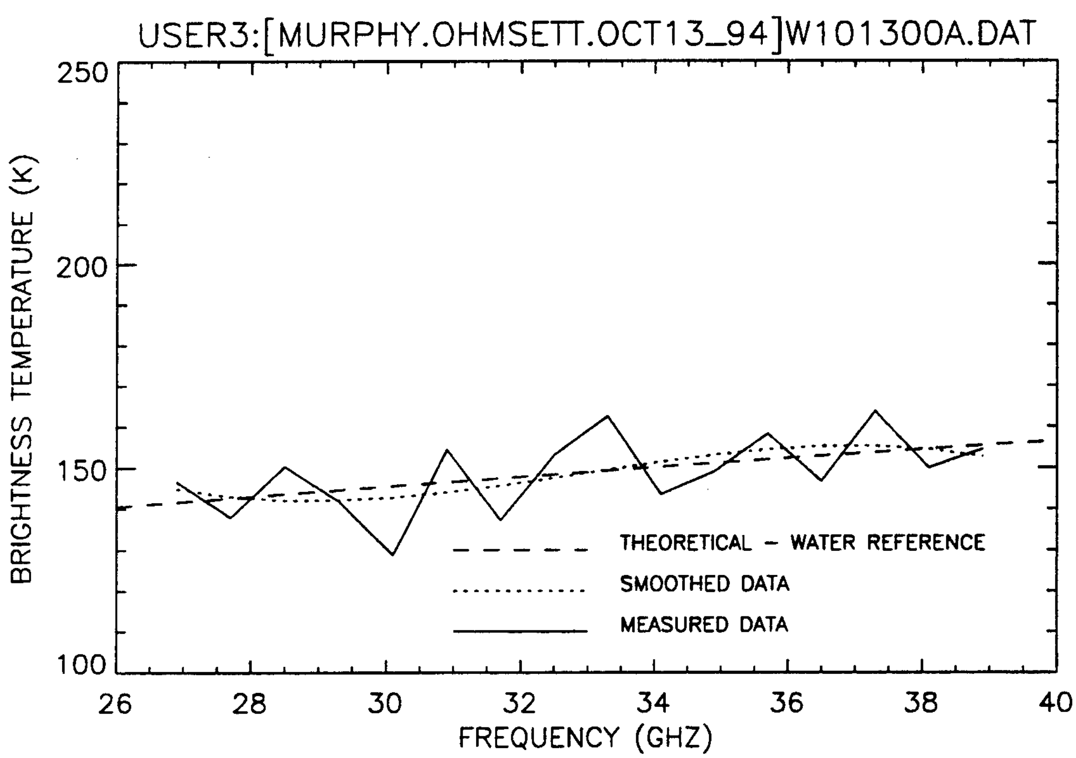

Figure D-48 T^B Versus Frequency Plot for Background Water, Wave Condition 2, 13 October 1994, Pass 1

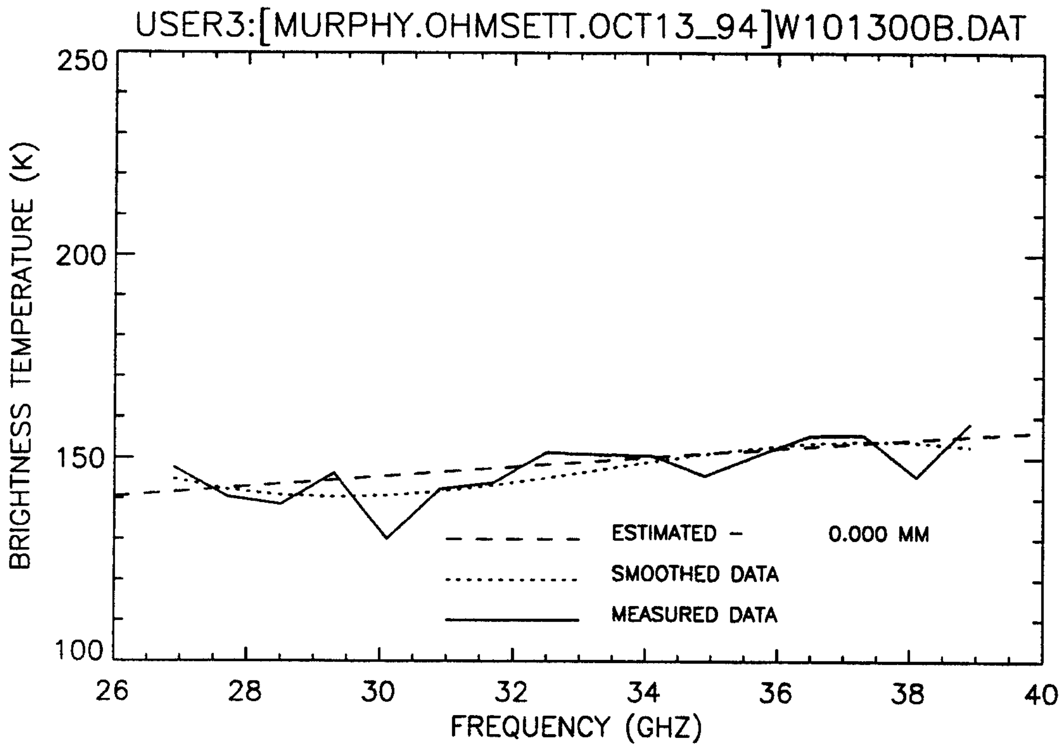

Figure D-49 T^B Versus Frequency Plot for Background Water, Wave Condition 2, 13 October 1994, Pass 2

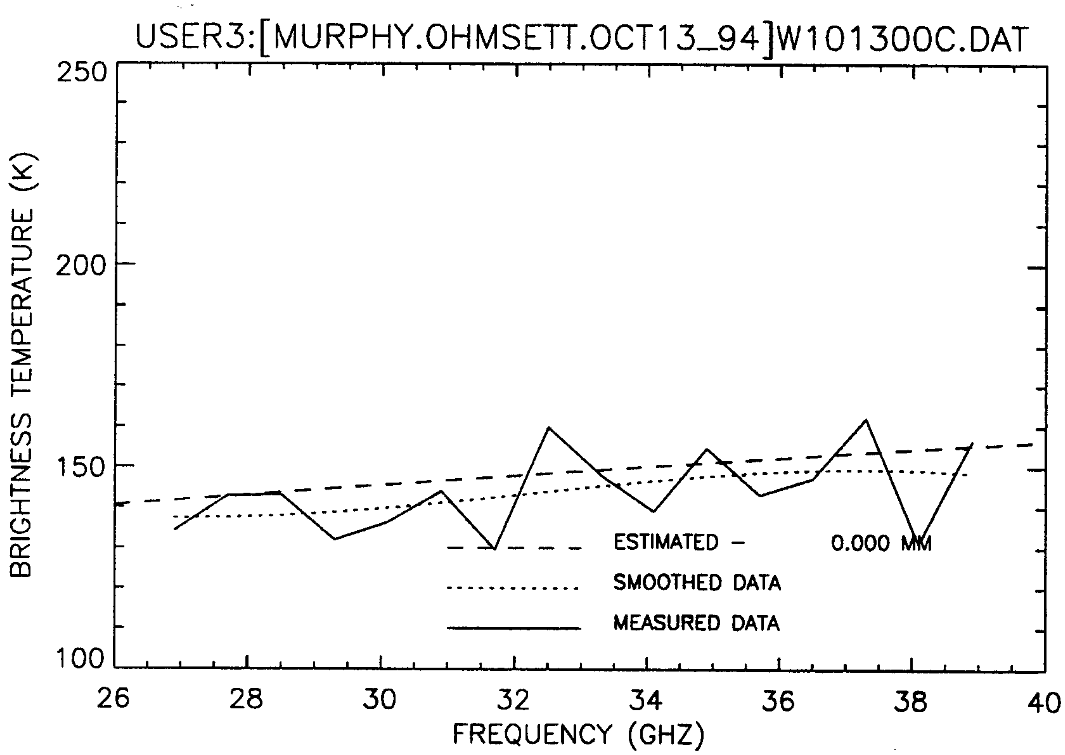

Figure D-50 T^B Versus Frequency Plot for Background Water, Wave Condition 2, 13 October 1994, Pass 3

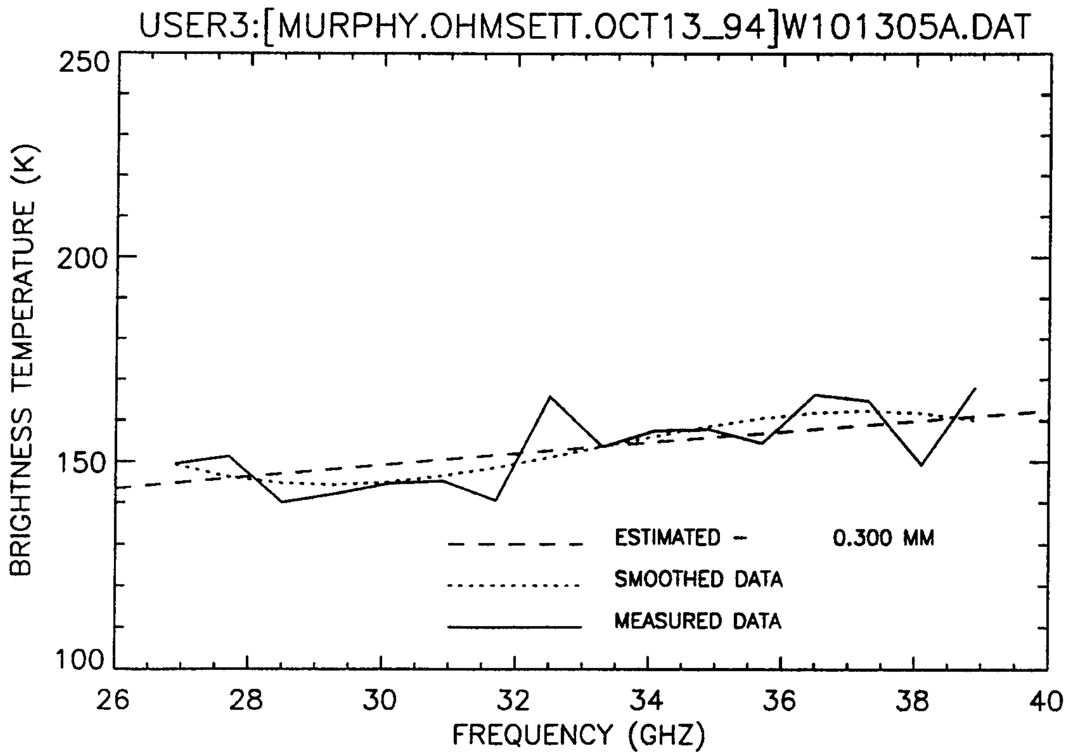

Figure D-51 T^B Versus Frequency Plot for 0.5 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 1

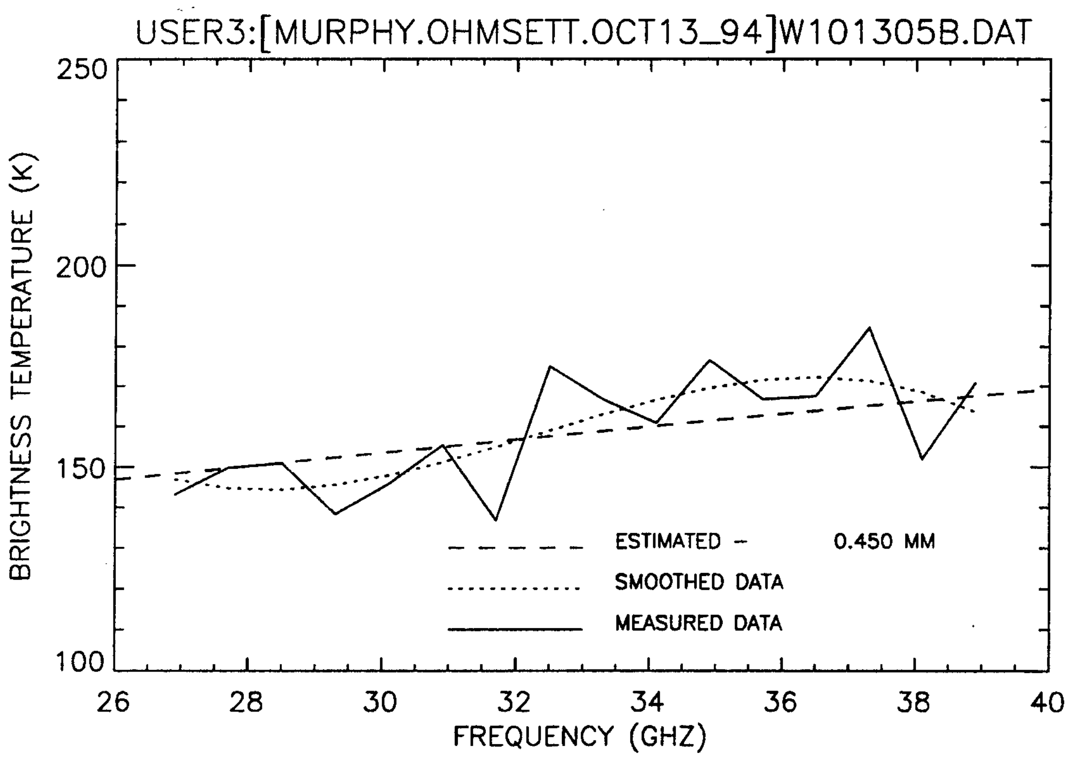

Figure D-52 T^B Versus Frequency Plot for 0.5 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 2

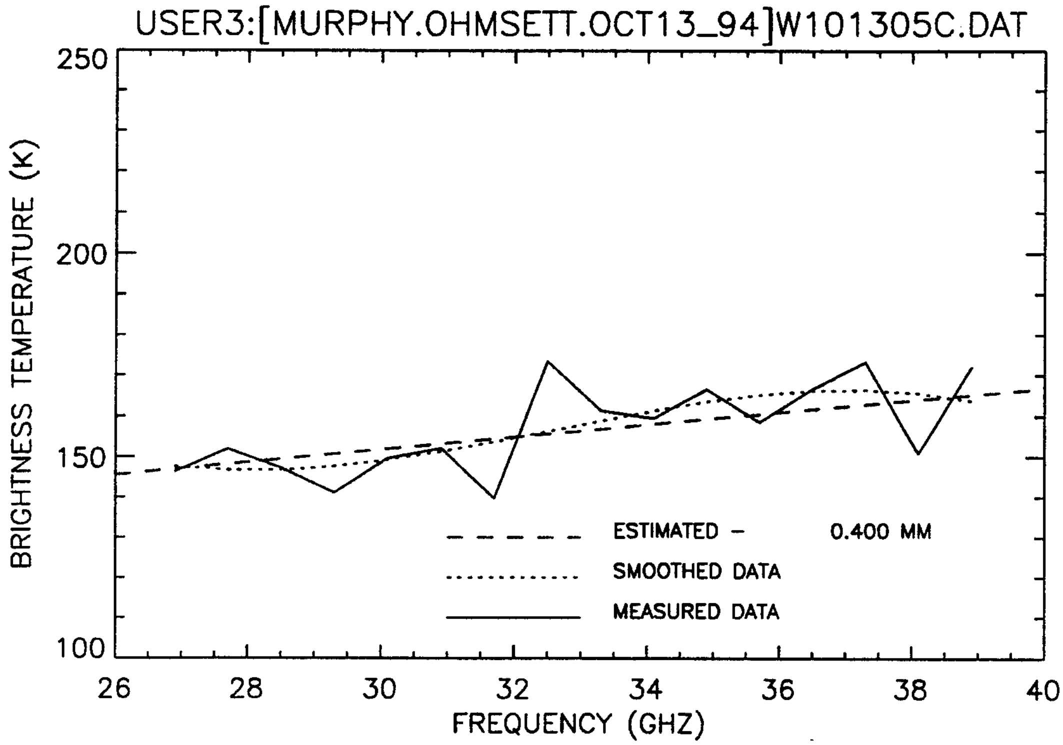

Figure D-53 T^B Versus Frequency Plot for 0.5 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 3

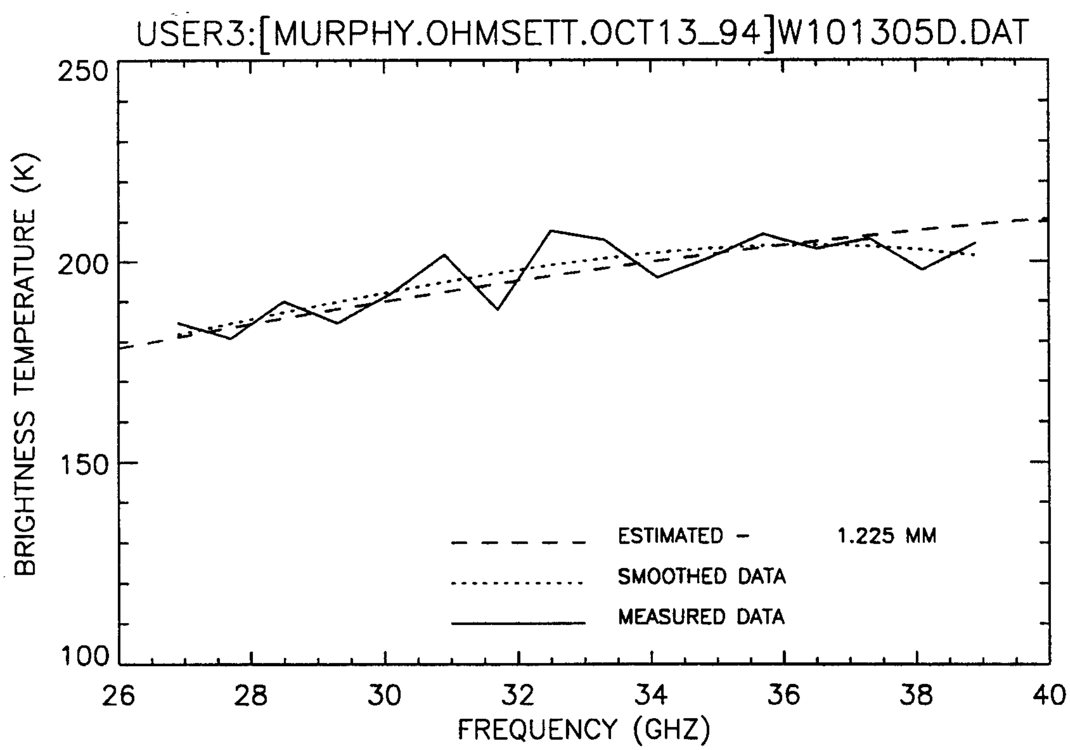

Figure D-54 T^B Versus Frequency Plot for 0.5 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 4

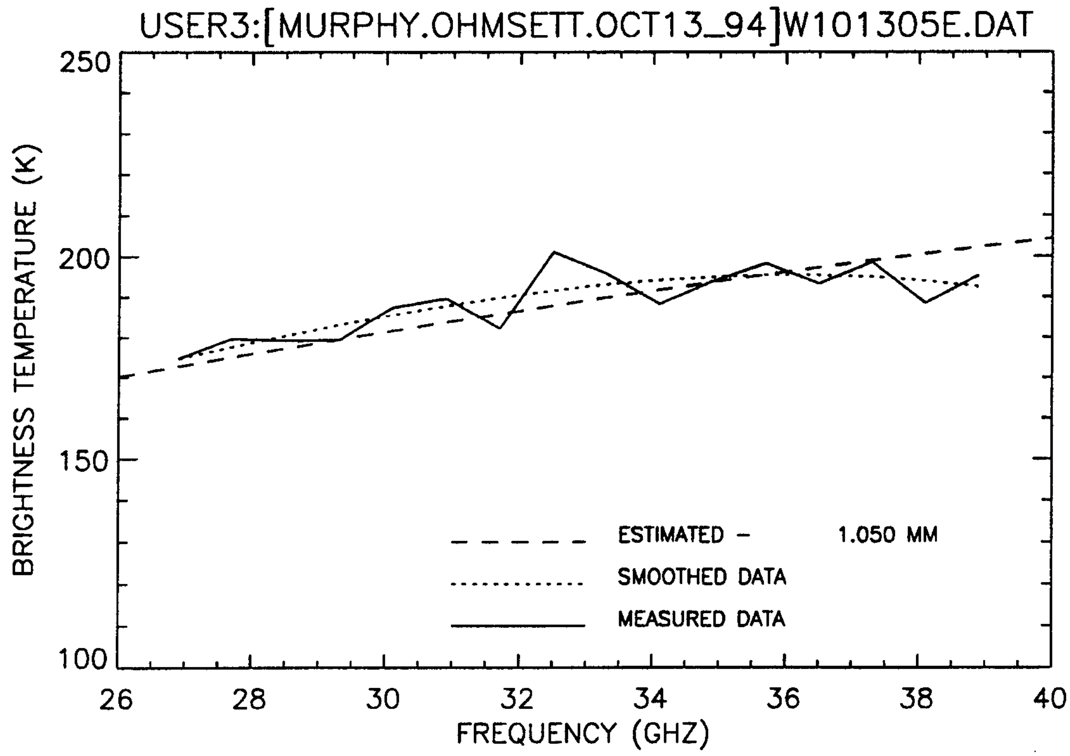

Figure D-55 T^B Versus Frequency Plot for 0.5 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 5

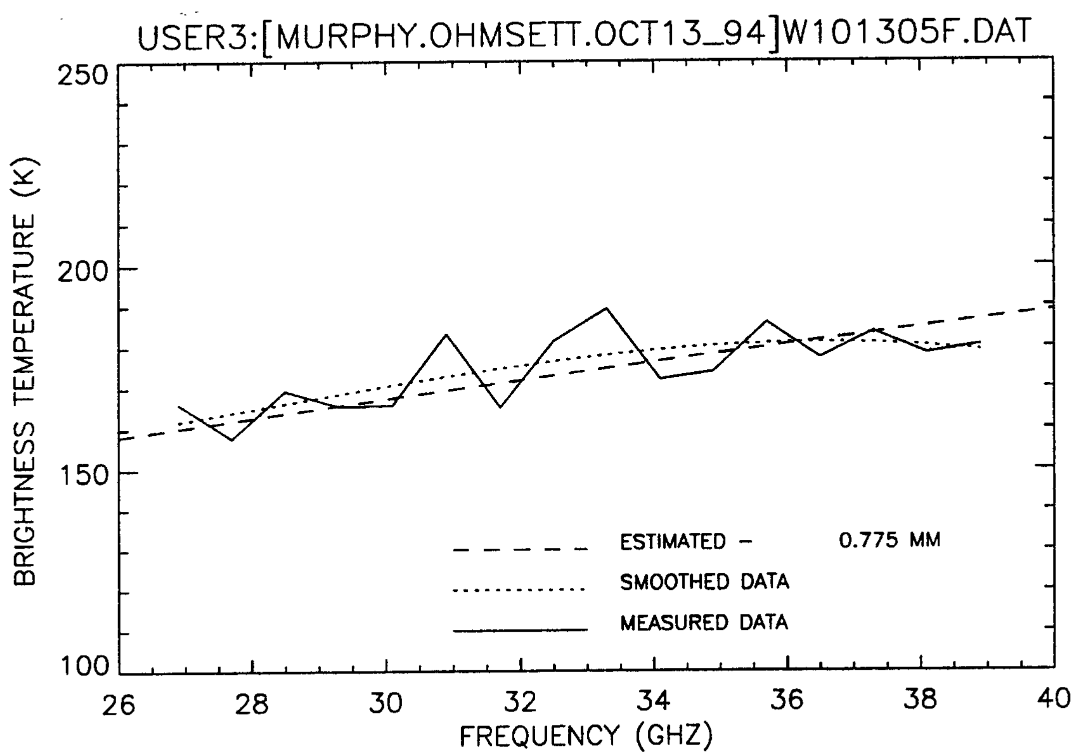

Figure D-56 T^B Versus Frequency Plot for 0.5 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 6

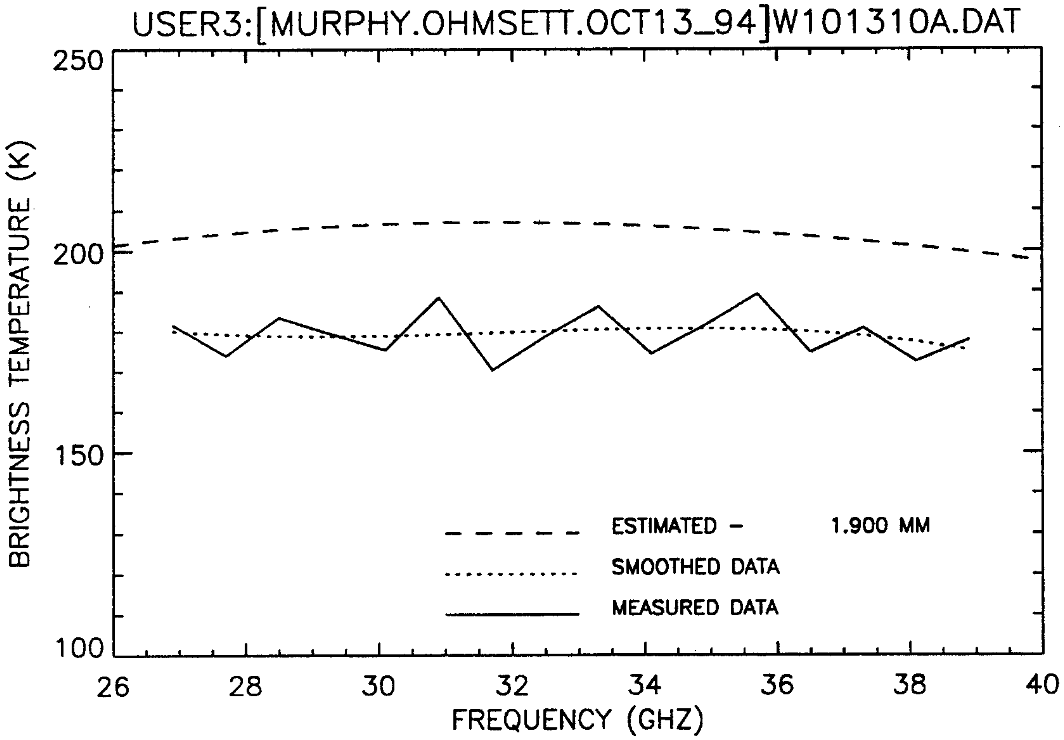

Figure D-57 T^B Versus Frequency Plot for 1.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 1

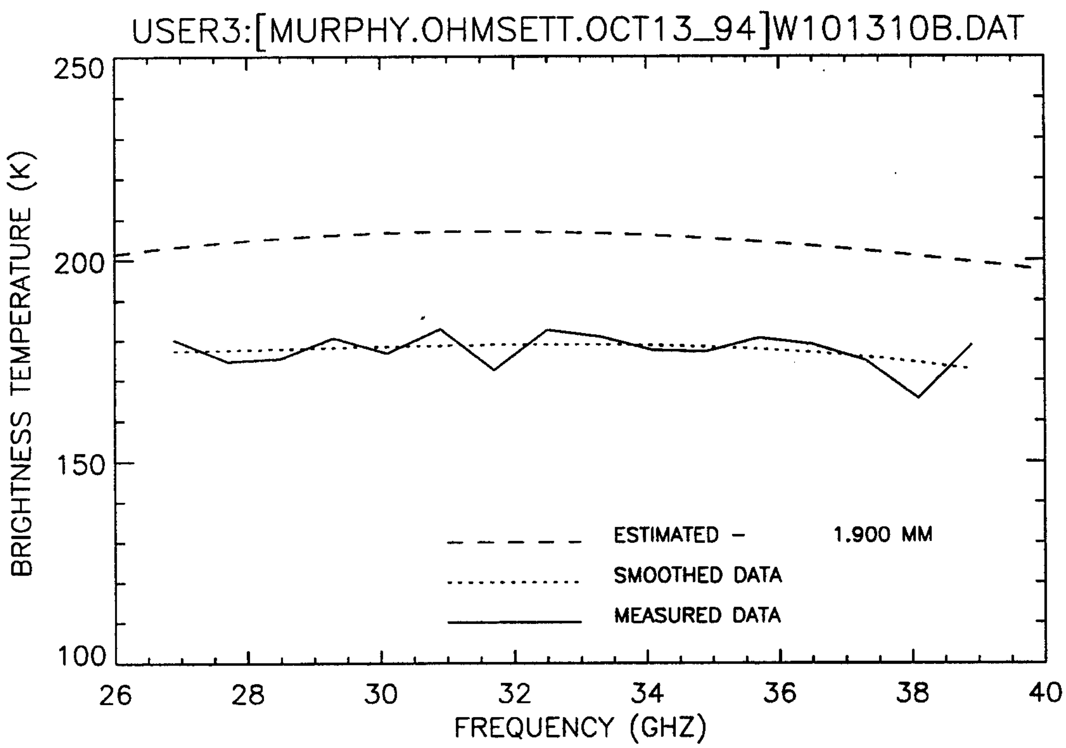

Figure D-58 T^B Versus Frequency Plot for 1.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 2

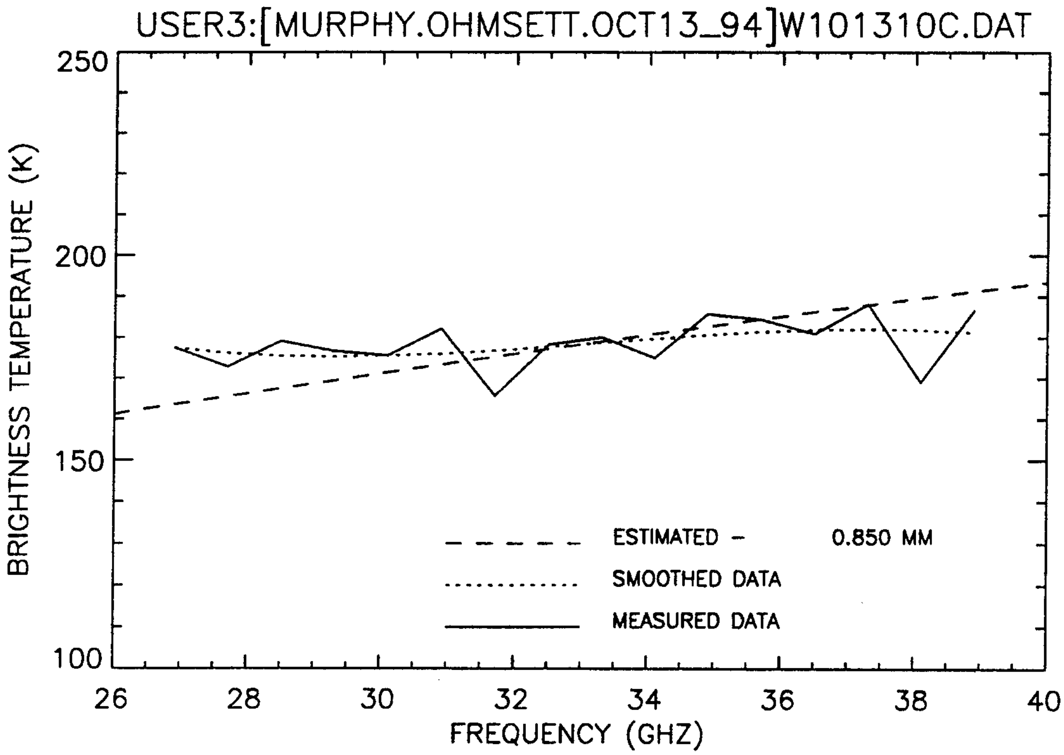

Figure D-59 T^B Versus Frequency Plot for 1.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 3

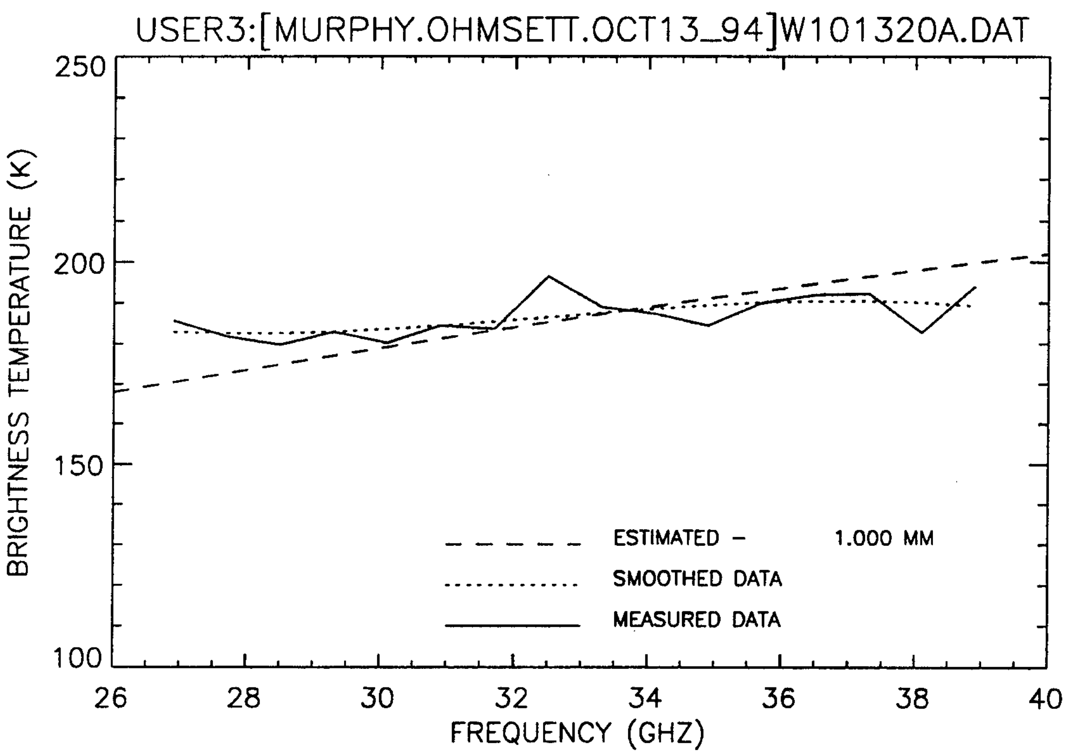

Figure D-60 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 1

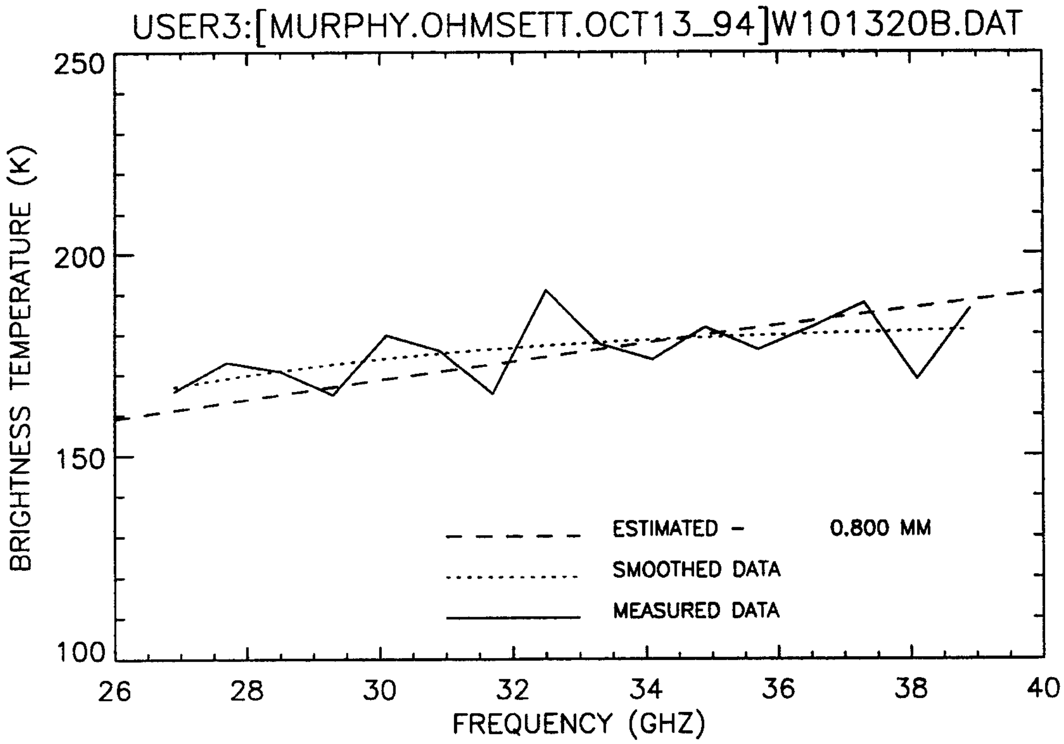

Figure D-61 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 2

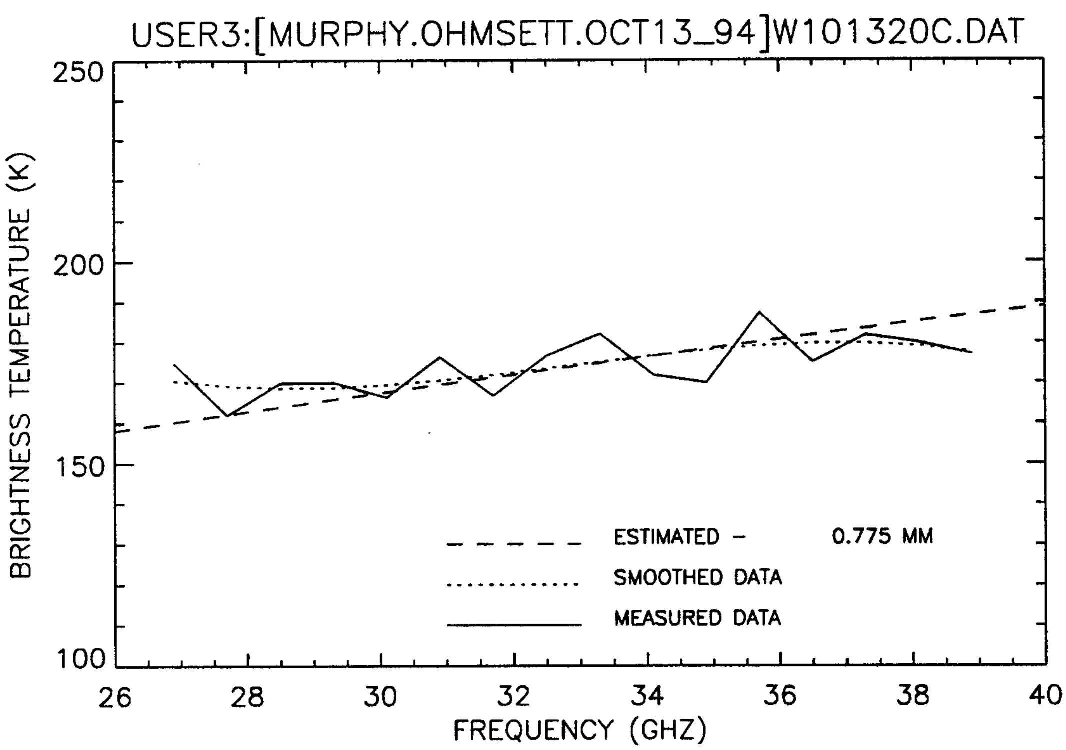

Figure D-62 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 3

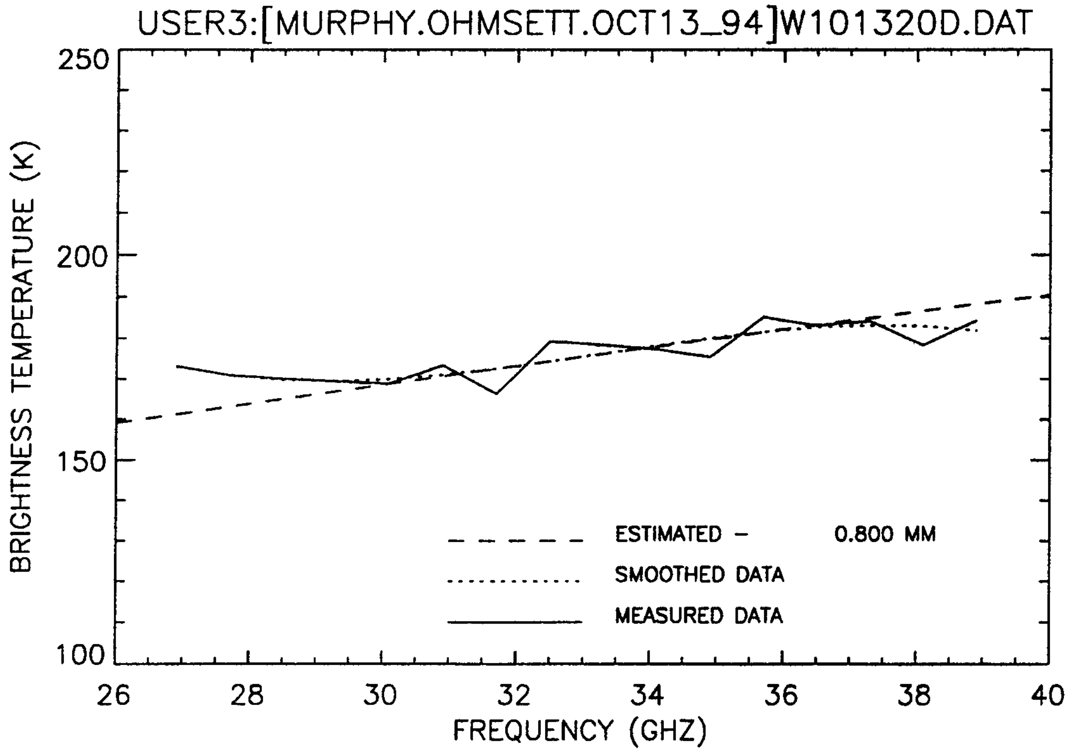

Figure D-63 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 4

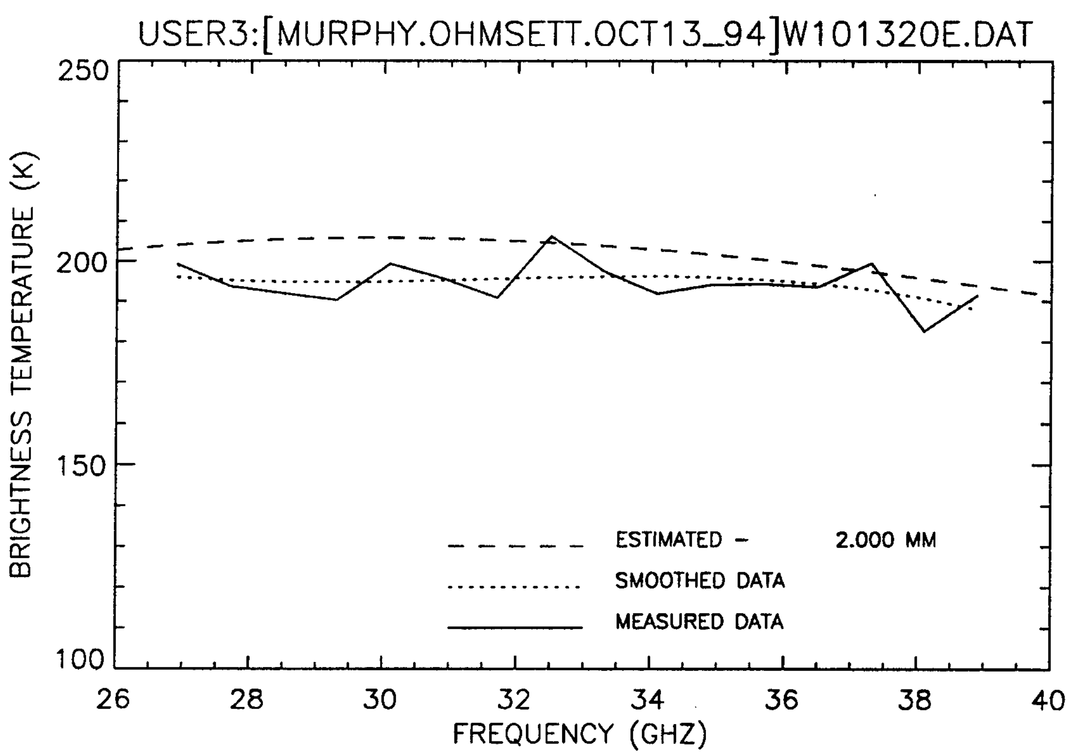

Figure D-64 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 5

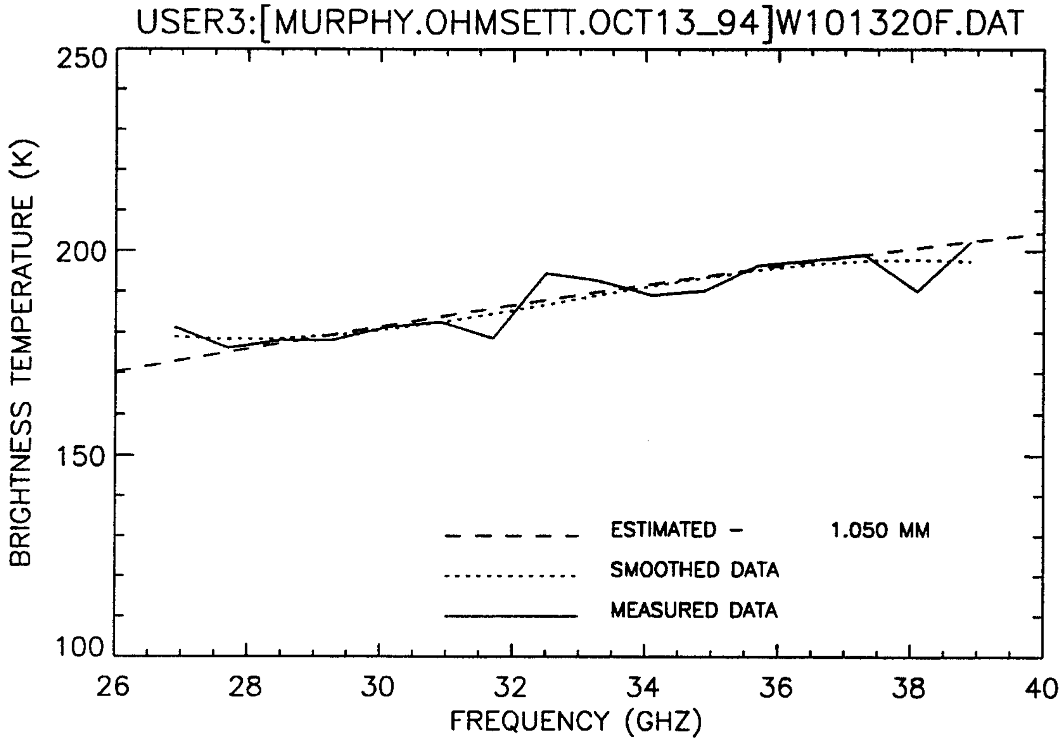

Figure D-65 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 6

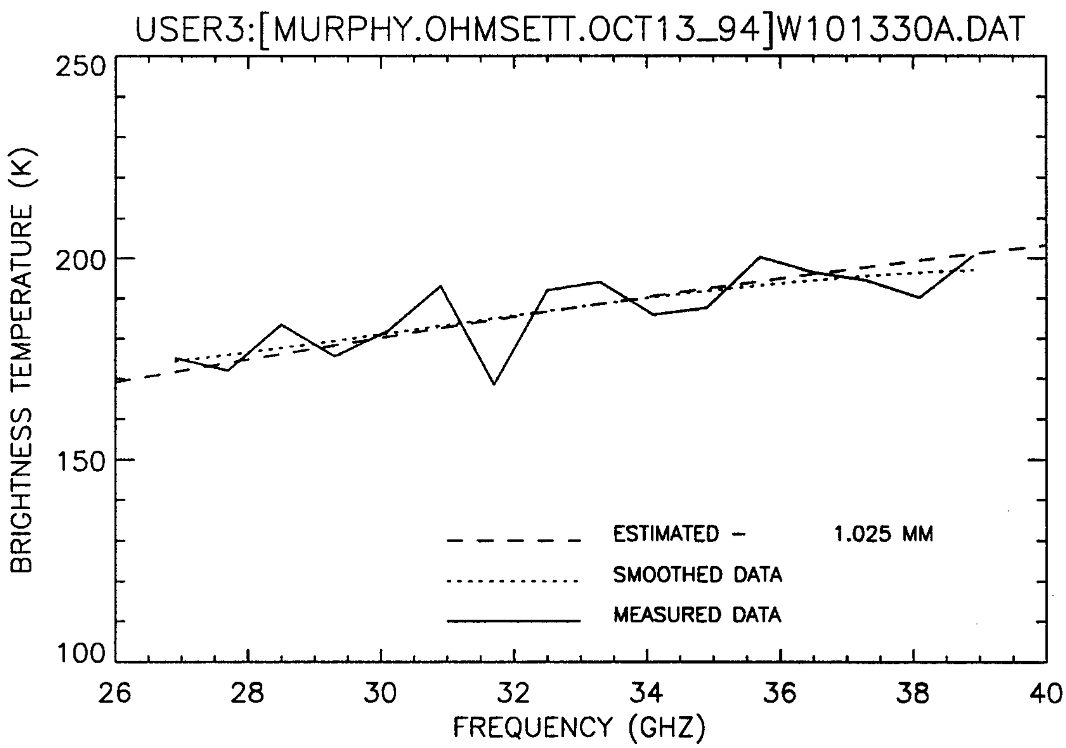

Figure D-66 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 1

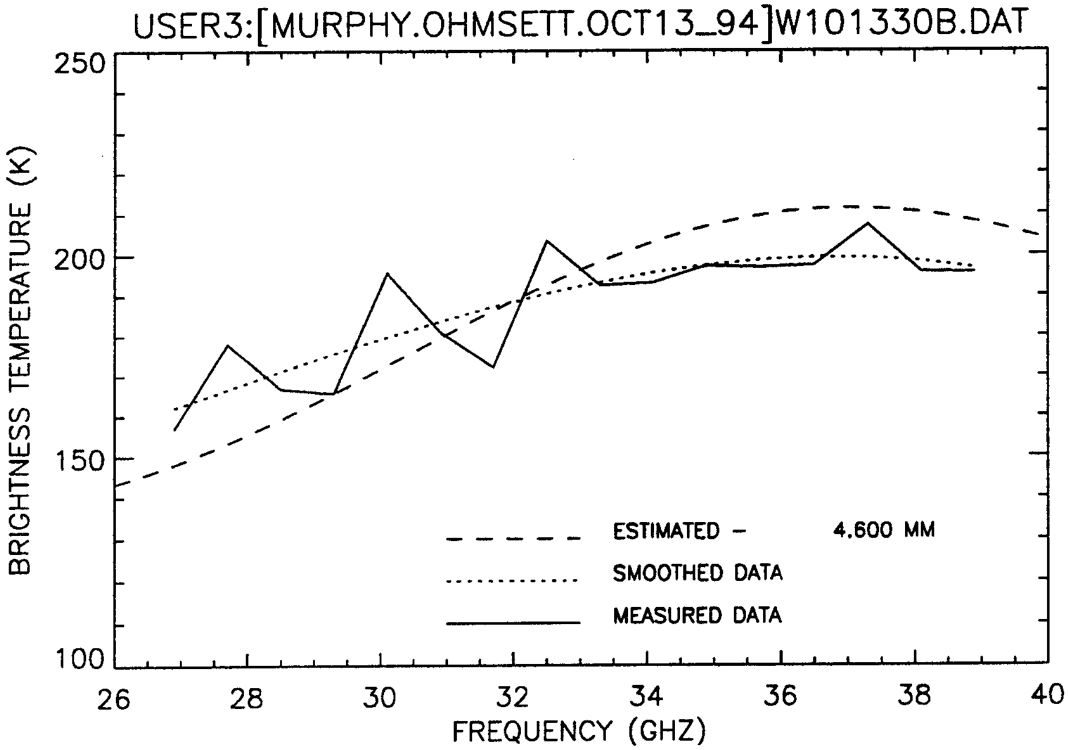

Figure D-67 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 2

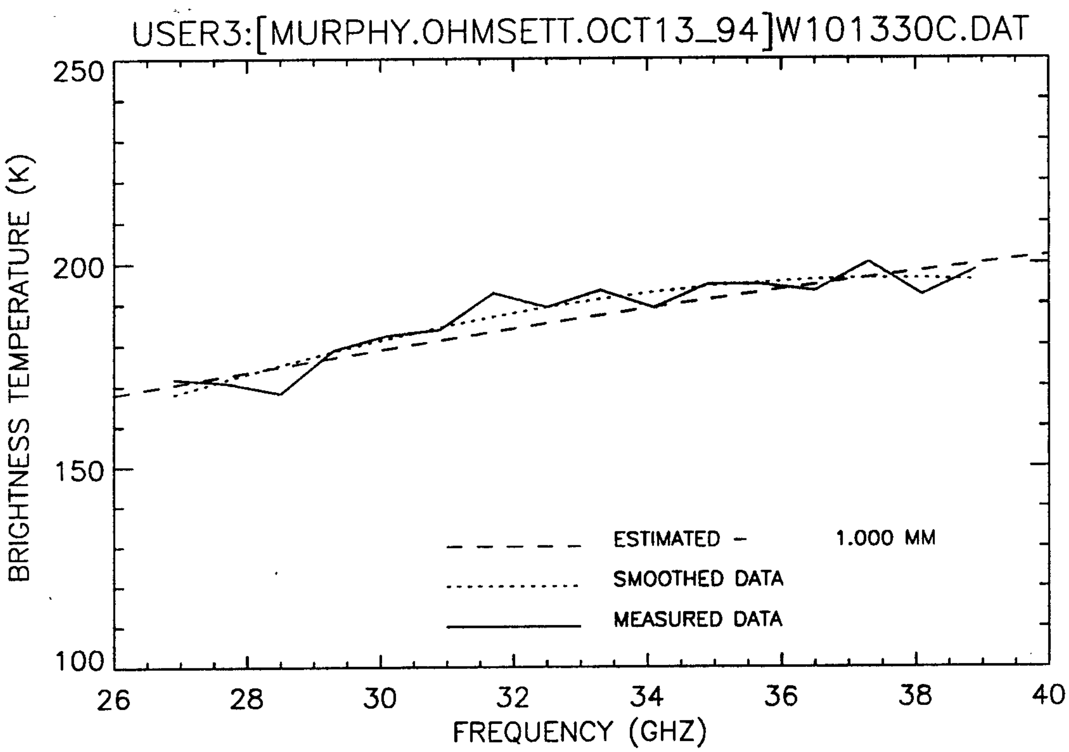

Figure D-68 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 3

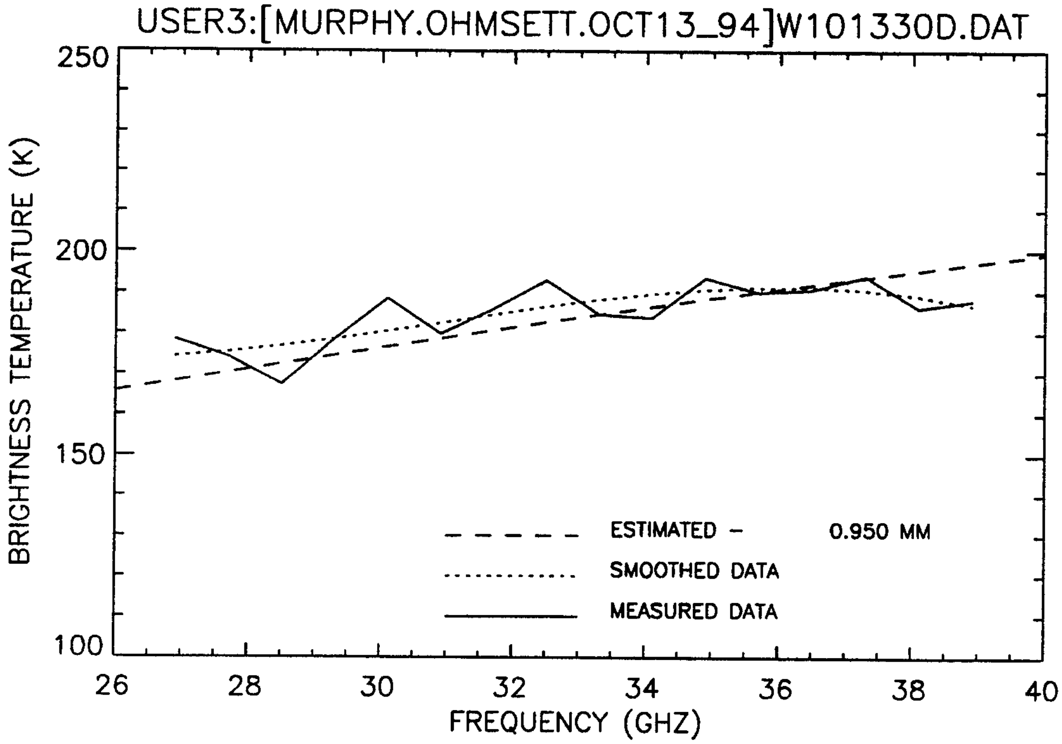

Figure D-69 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 4

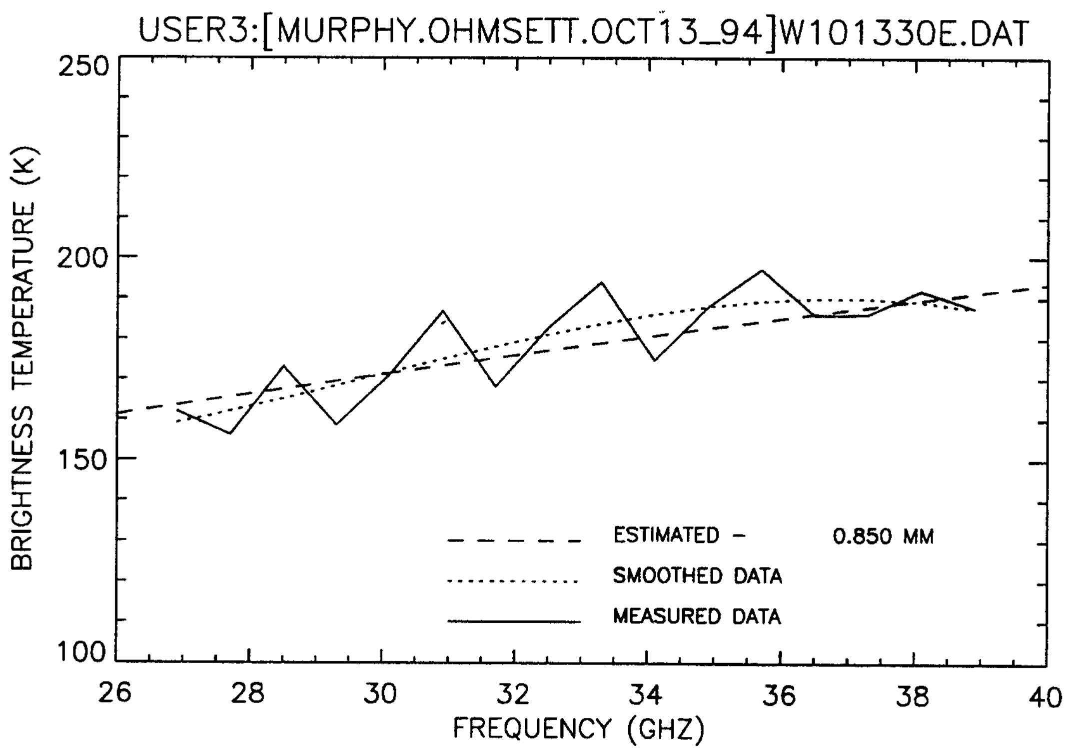

Figure D-70 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 5

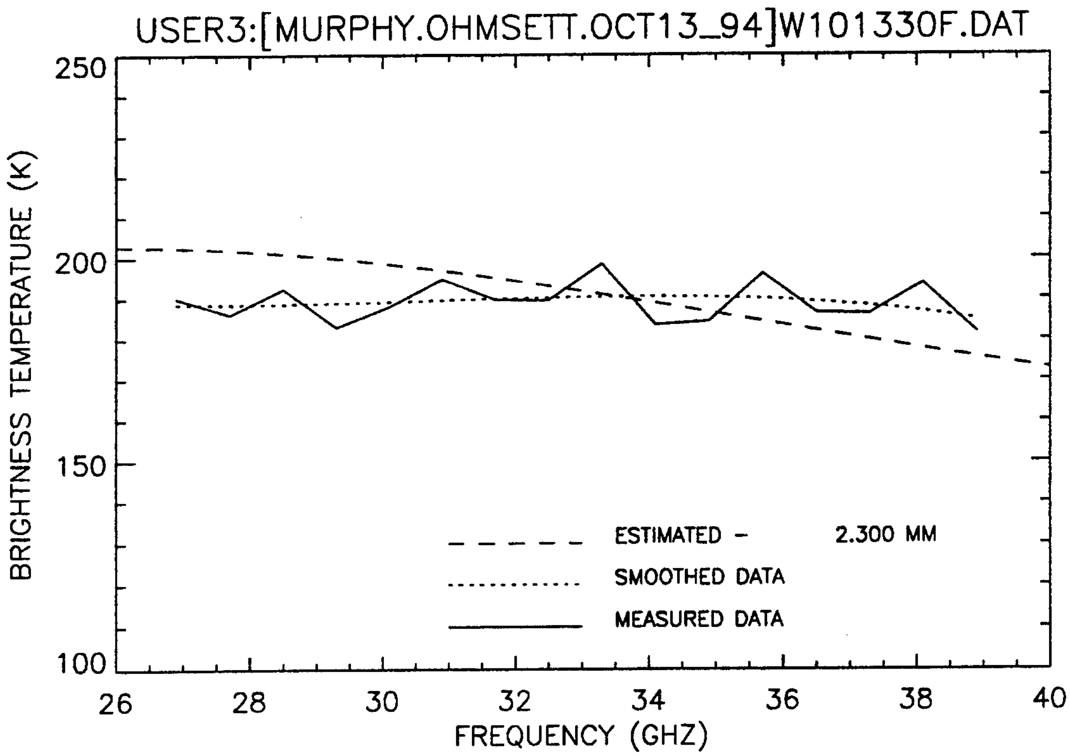

Figure D-71 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 6

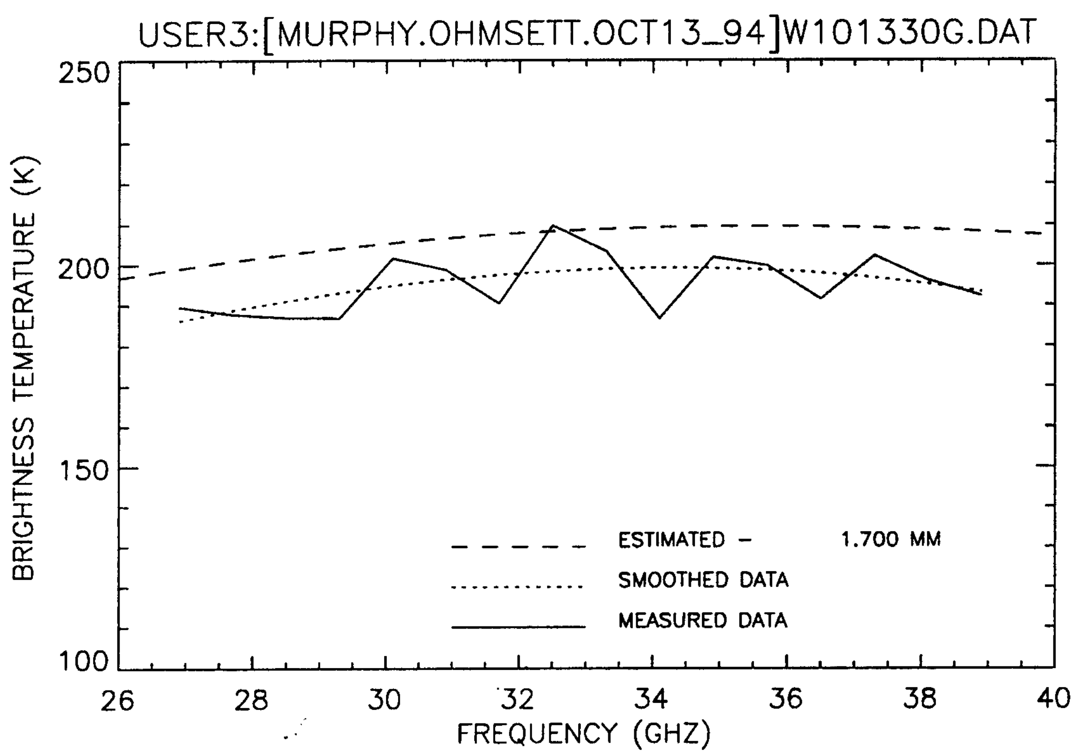

Figure D-72 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 7

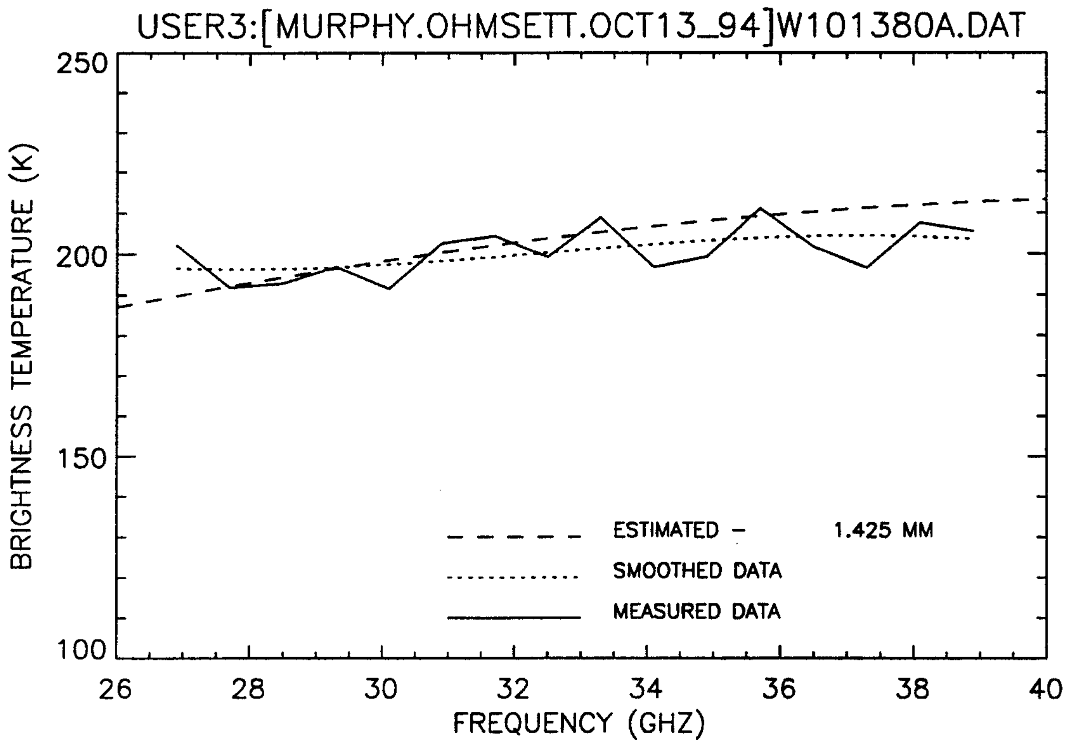

Figure D-73 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 1

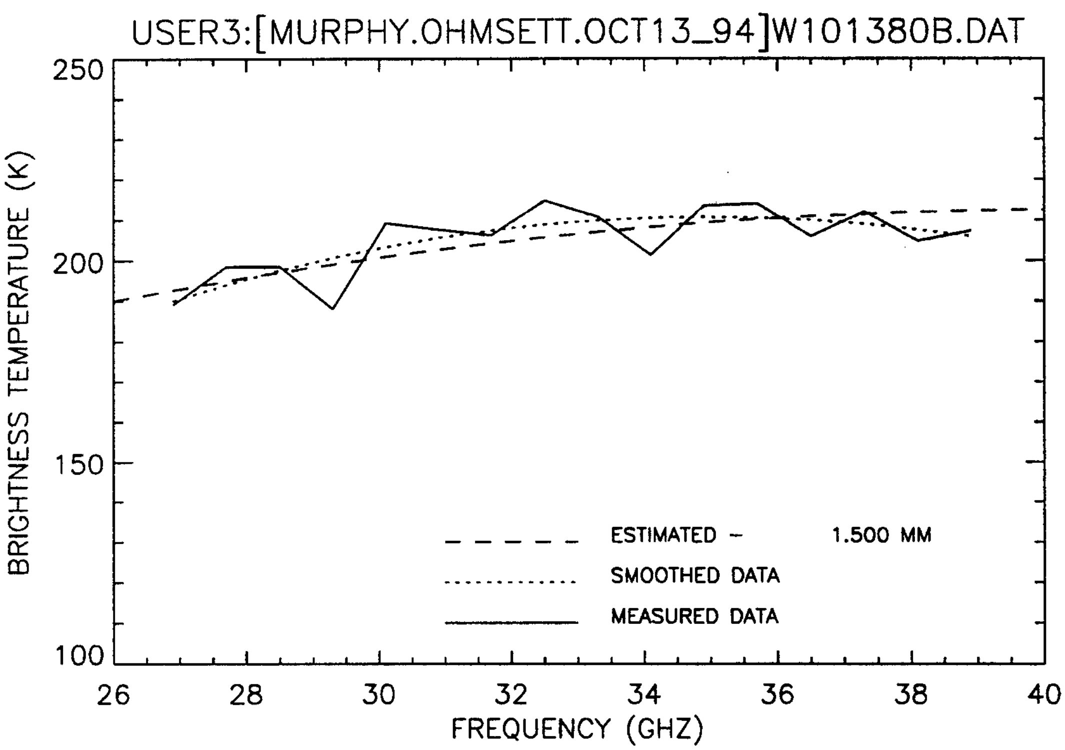

Figure D-74 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 2

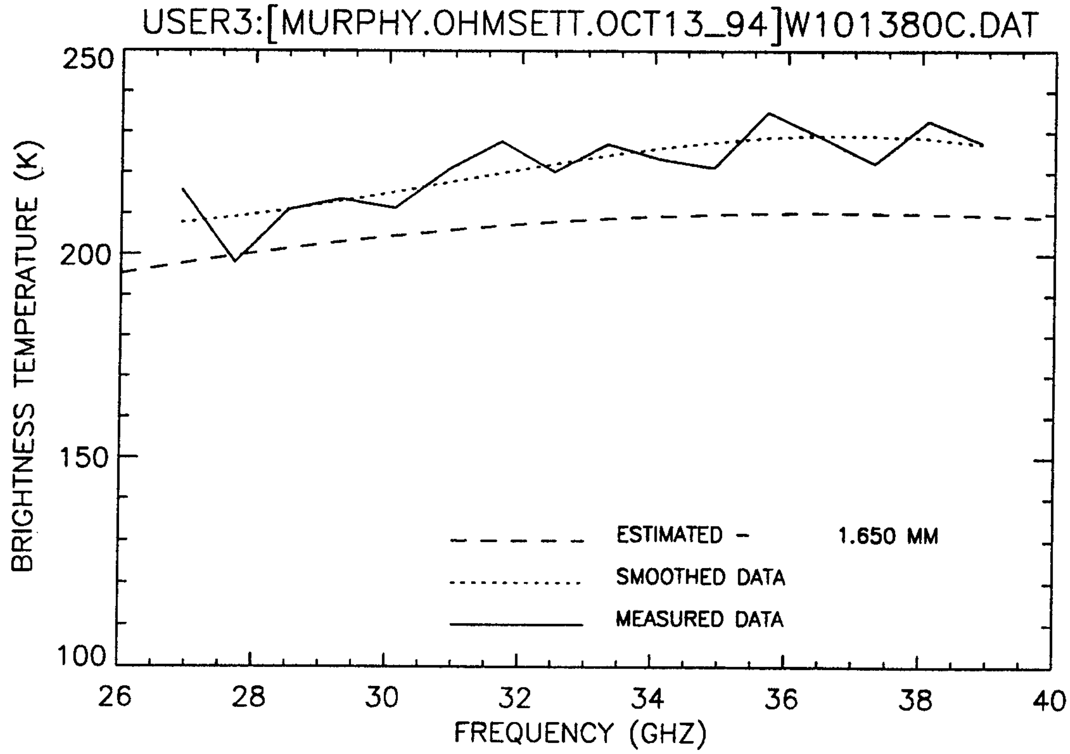

Figure D-75 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 3

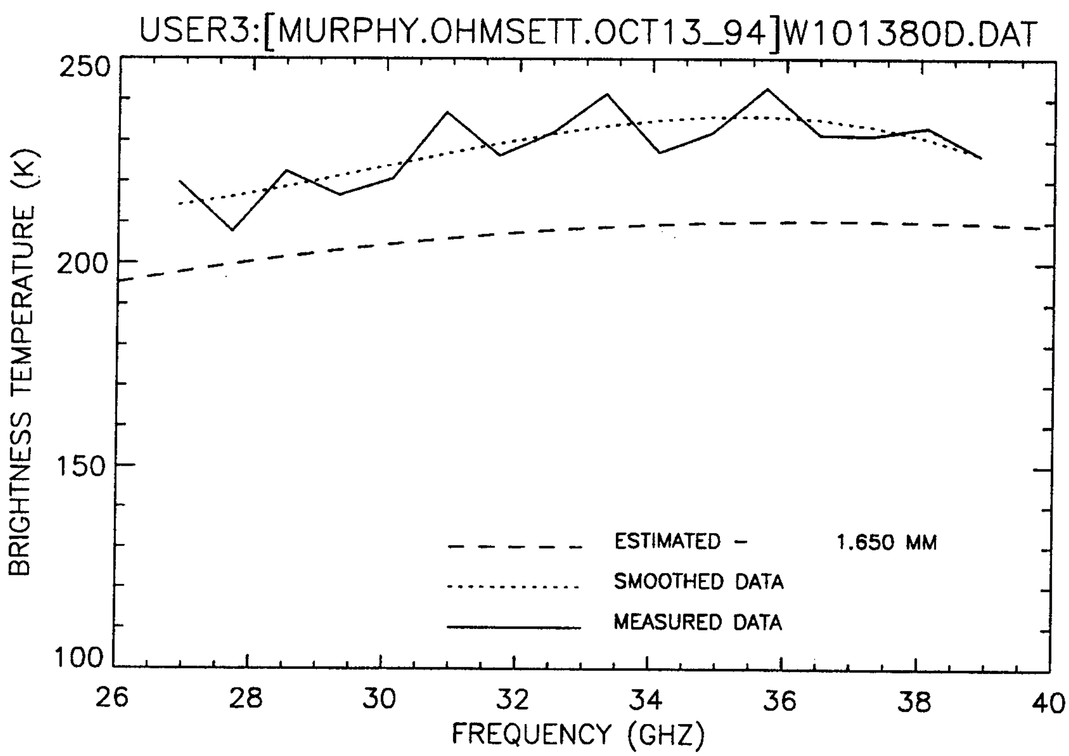

Figure D-76 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Wave Condition 2, 13 October 1994, Pass 4

The H-data files were collected on 14 October 1996; these oil targets are the same targets used on 13 October and had remained in the OHMSETT tank overnight. The OHMSETT main bridge was positioned over the clear water pool to obtain water background measurements.

H101400A - This curve is a poor match to the algorithm estimate of 0.0 mm. Since the estimate curve has a higher overall T^B than the measurement curve, it can be assumed that the FSR electronics and active heat sink were still warming-up.

H101400B - This curve is a good-to-excellent match to the algorithm estimate of 0.0 mm.

H101400C - This curve was chosen as reference water temperature for this data set. This was the last of the water reference measurements made and it appeared that the instrument was still warming-up during the earlier measurements.

H101400D - This curve is a fair match to the algorithm estimate of 0.0 mm.

The next three measurements were taken at the north side of the 0.5 mm oil target pool. The oil appears to be uniformly distributed across the target surface; however, the red dye coloration of this pool is extremely pale so it was difficult to detect any thickness gradients. The surface of the target is extremely flat because there were no capillary waves due to wind.

H101405A - This curve is an excellent match to the algorithm estimate of 0.750 mm.

H101405B - This curve is an excellent match to the algorithm estimate of 0.725 mm.

H101405C - This curve is a fair match to the algorithm estimate of 0.725 mm.

The OHMSETT main bridge was moved so that the FSR was now aimed in the center of the 0.5 mm oil target pool.

H101405D - This curve is a good match to the algorithm estimate of 0.475 mm.
H101405E - This curve is an excellent match to algorithm estimate of 0.5 mm.
H101405F - This curve is an excellent match to the algorithm estimate of 0.525 mm.

The OHMSETT main bridge was again moved, and the FSR measured the oil target at the south end of this pool.

H101405G - This curve is a good match to the algorithm estimate of 0.325 mm.
H101405H - This curve is a good match to the algorithm estimate of 0.275 mm.

The following measurements are from the north end of the 1.0 mm oil target pool. A small volume of oil had been lost from this pool during the wave 2 measurements on 13 October. The surface of the target is extremely flat because there were no capillary waves due to wind. The oil target appears slightly thicker in the north end of the pool.

H101410A - This curve is a fair match to the algorithm estimate of 1.125 mm. The slope matches a 1.2 mm curve well up until the 35 GHz point where the curve starts a downward trend.
H101410B - This curve is a fair match to the algorithm estimate of 1.175 mm. The curve has a good shape match to 1.6 mm, but overall the T^B seems to be too low.
H101410C - This curve is a fair match to the algorithm estimate of 1.15 mm. The curve has a good shape match to 1.6 mm, the correlation result, but overall the T^B seems to be too low.

The OHMSETT main bridge was moved south so the FSR could measure the center of the 1.0 mm oil target pool.

H101410D - This curve is an excellent match to the algorithm estimate of 0.5 mm.

H101410E - This curve is an excellent match to the algorithm estimate of 0.5 mm.

The OHMSETT main bridge was moved to allow the FSR to measure the oil target on the south side of the oil target pool.

H101410F - This curve is an excellent match to the algorithm estimate of 0.4 mm.

H101410G - This curve is an excellent match to the algorithm estimate of 0.375 mm.

The OHMSETT main bridge was moved to the north part of the 2.0 mm oil target pool. The north side of the oil target appeared thicker, and some type of dust or pollen had settled on the surface of the entire oil target.

H101420A - This curve is a poor match to the algorithm estimate of 3.325 because it has no inflection point. The overall T^B is too low to be a 2.0 mm curve. The measurement seems flat, not up-sloping like the characteristic of curves less than 1.0 mm. This measurement is probably in the 3.3 - 3.5 mm range, but the curve doesn't show enough inflection or amplitude variation to positively identify. The result is inconclusive.

H101420B - This curve is a fair match to the algorithm estimate of 3.35 mm. The curve exhibits a small degree of inflection. No better visual-based estimate is found.

The OHMSETT main bridge was moved south to the center of the 2.0 mm oil target pool.

H101420C - This curve is a poor match to the algorithm estimate of 2.95 mm. The curve is flat, and visually doesn't match any estimates well. The result is inconclusive; however, the algorithm estimate seems to be consistent with related measurements.

H101420D - This curve is a fair match to the algorithm estimate of 3.0 mm. No better visual comparison estimates were found.

The OHMSETT main bridge was moved to the south side of the 2.0 mm oil target pool.

H101420E - This curve is a poor match to the algorithm estimate of 2.425 mm. The curve appears quite flat, with shape is similar to a 2.1 mm estimate (plotted); however, overall T^B seems too low.

H101420F - This curve is a good match to the algorithm estimate of 2.275 mm. The actual measured data has some very 'warm' points between 32 - 33 GHz and 35 - 36 GHz, possibly due to sun glinting from the surface of the pool into the an antenna feed horn. (The sun is a very hot source, approximately 5000° K, so any small fraction of sun glinting during a measurement could cause an anomalous result.)

H101420G - This curve is a poor match to the algorithm estimate of 2.325 mm. The flatness of the curve is more likely associated with a 2.0 mm characteristic; however overall the T^B of the measured curve seems too low.

The measurements described above show disappointing results. It is not understood why these calm water measurements show a consistent flat response unless the pollen or dust on the surface changed the radiometric signature of the oil.

The OHMSETT main bridge was moved to measure the north side of the 3.0 mm oil target pool. The pool appeared to have a uniform oil thickness, and no capillary waves due to wind. There was considerably less dust/pollen on the oil surface of this oil target compared to the 2.0 mm target.

H101430A - This curve is a good match to the algorithm estimate of 3.9 mm.

H101430B - This curve is a good match to the algorithm estimate of 3.8 mm.

H101430C - This curve is a fair match to the algorithm estimate of 4.100 mm; however, an estimate of 4.225 mm seems to be a better match.

The main bridge was moved to measure the middle of the 3.0 mm oil target pool.

H101430D - This curve is a fair-to-excellent match to the algorithm estimate of 3.675 mm. The curve shows an excellent match at frequencies less than 34 GHz, while the curve seems to fall off in amplitude above 34 GHz compared to the estimate.

H101430E - This curve is a good match to the algorithm estimate of 3.575 mm. The shape of the measured data curve is more linear than that for the estimated curve.

The main bridge was moved to measure the south side of the 3.0 mm oil target pool.

H101430F - This curve is a good-to-excellent match to algorithm estimate of 3.525 mm, although the amplitude of the measured curve falls off after 36 GHz.

H101430G - This curve is a good match to the algorithm estimate of 3.3 mm, although somewhat flatter.

The OHMSETT main bridge was moved to measure the north side of the 8.0 mm oil target pool.

H101480A - This curve is a good match to the algorithm estimate of 8.625 mm, although the peak amplitude of the measured curve does not reach the same high value as the theoretical prediction. The measured data seems to match the estimated curve better than the match between the estimated and smoothed data curve.

H101480B - This curve is a good match to the algorithm estimate of 8.825 mm, although the peak amplitude of the measured curve does not reach the same high value as the theoretical prediction. The measured data seems to match the estimated curve better than the match between the estimated and smoothed data curve.

H101480C - This curve is a good match to the algorithm estimate of 8.725 mm, although the peak amplitude of the measured curve does not reach the same high value as the theoretical prediction. The measured data seems to match the estimated curve better than the match between the estimated and smoothed data curve.

H101480D - This curve is a good match to the algorithm estimate of 8.775 mm, although the peak amplitude of the measured curve does not reach the same high value as the theoretical prediction. The measured data seems to match the estimated curve better than the match between the estimated and smoothed data curve.

The main bridge was moved to measure the oil target in the center of the 8.0 mm oil target pool.

H101480E - This curve is a good match to the algorithm estimate of 8.7 mm. The raw data, in fact, are in excellent agreement with the theoretical prediction. The measured data seems to match the estimated curve better than the match between the estimated and smoothed data curve.

H101480F - This curve is a good match to the algorithm estimate of 8.625 mm. The raw data again are in excellent agreement with the theoretical prediction. The measured data seems to match the estimated curve better than the match between the estimated and smoothed data curve.

The OHMSETT main bridge was moved to the south side of the 8.0 mm oil target pool.

H101480G - This curve is a good match to algorithm estimate of 8.75 mm. The raw data again are in excellent agreement with the theoretical prediction. The measured data seems to match the estimated curve better than the match between the estimated and smoothed data curve.

H101480H - This curve is a good match to the algorithm estimate of 8.6 mm. The raw data again are in excellent agreement with the theoretical prediction. The measured data seems to match the estimated curve better than the match between the estimated and smoothed data curve.

Many of the raw 8.0 mm data sets matched the theoretical T^B versus frequency curves better than the smoothed polynomial fitting function. This is because the polynomial function fits a least-squares, third order polynomial curve to the raw data, while at 8 mm oil thickness, the T^B versus frequency relationship becomes distinctly sinusoidal over the 26 to 40 GHz FSR band. Future algorithm development should explore sinusoidal fitting functions, but the polynomial function was judged to be adequate for most of the data collected during this test.

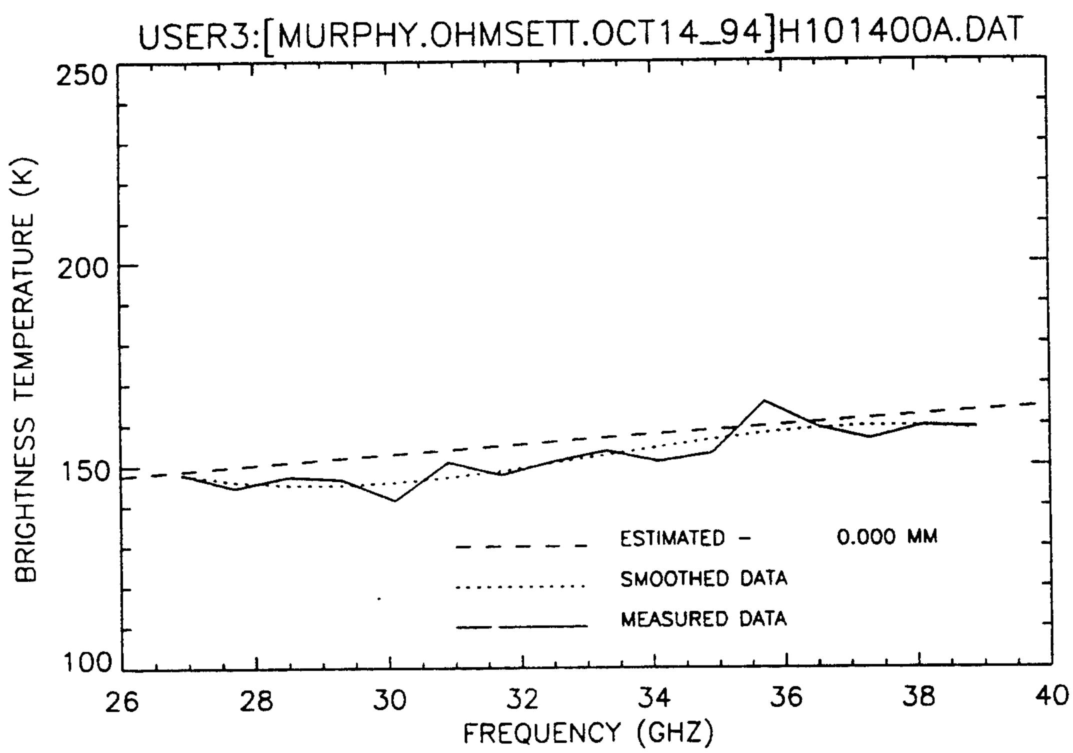

Figure D-77 T^B Versus Frequency Plot for Background Water, 14 October 1994, Pass 1

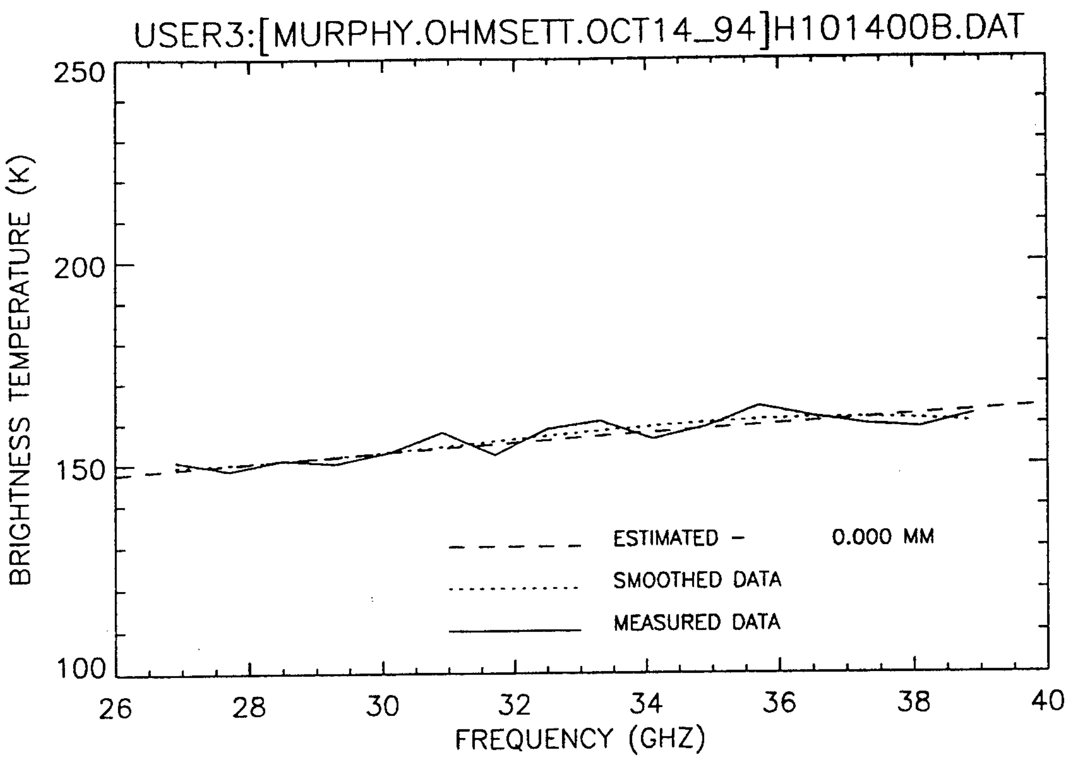

Figure D-78 T^B Versus Frequency Plot for Background Water, 14 October 1994, Pass 2

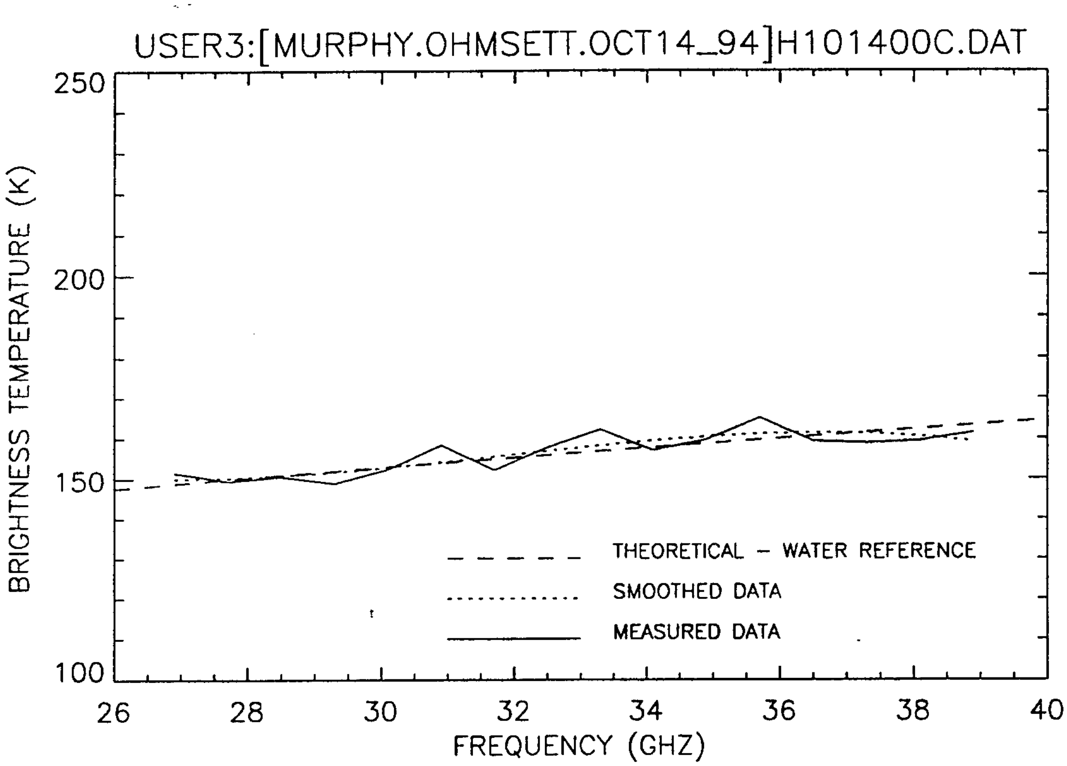

Figure D-79 T^B Versus Frequency Plot for Background Water, 14 October 1994, Pass 3

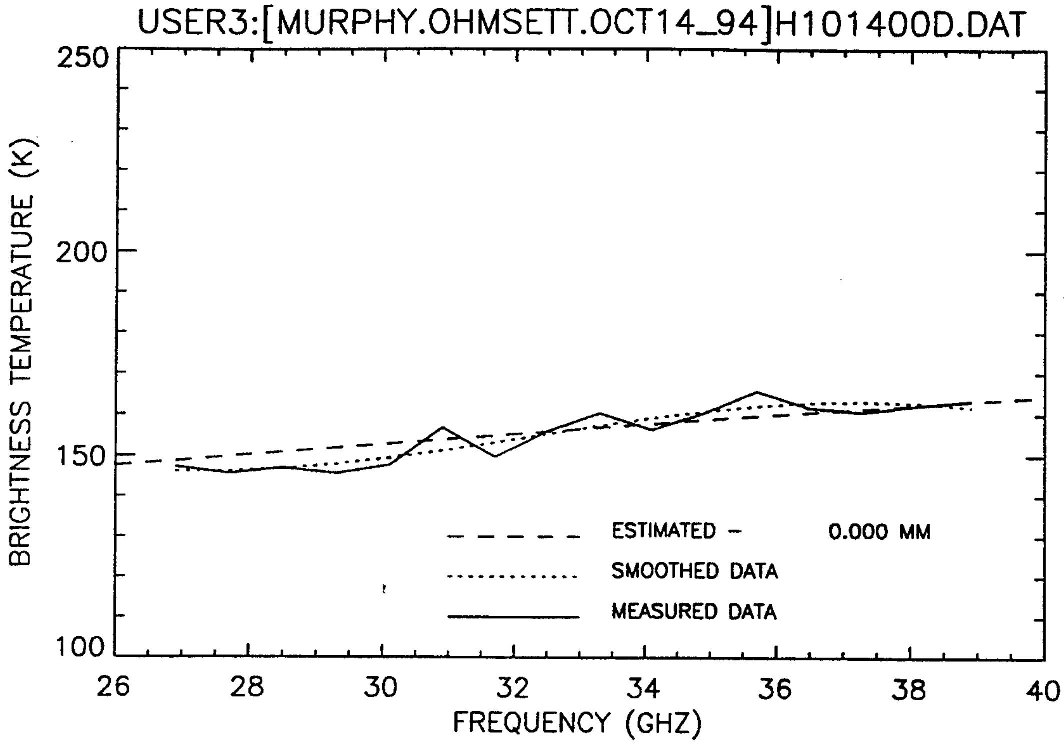

Figure D-80 T^B Versus Frequency Plot for Background Water, 14 October 1994, Pass 4

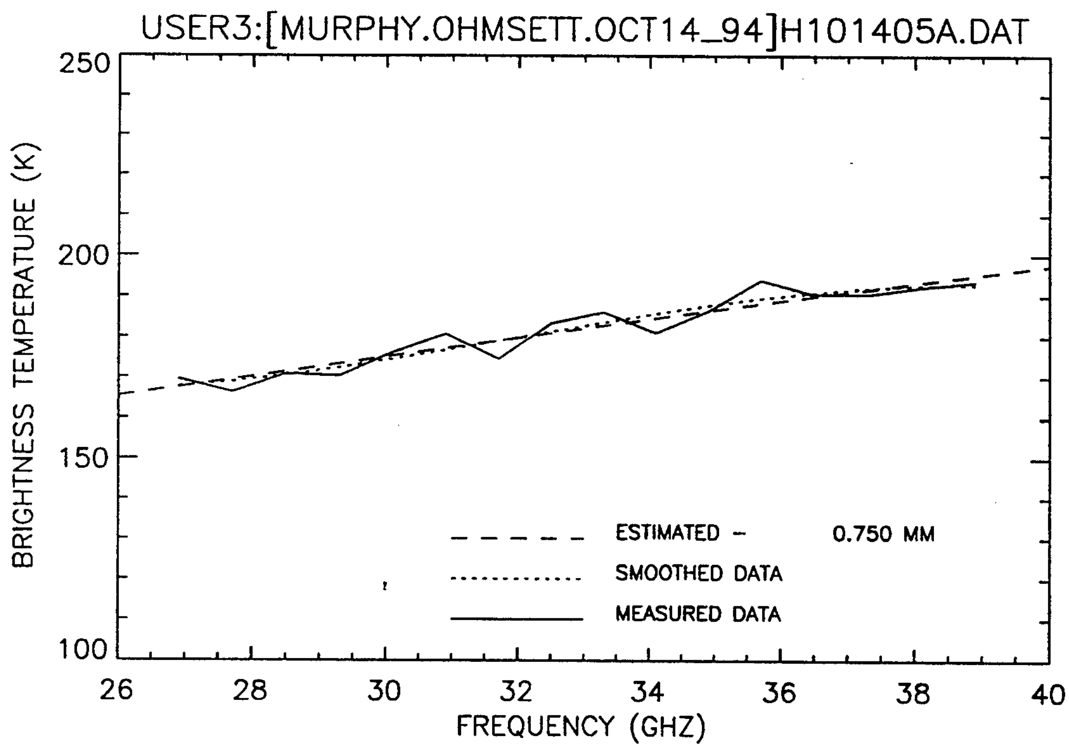

Figure D-81 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 1

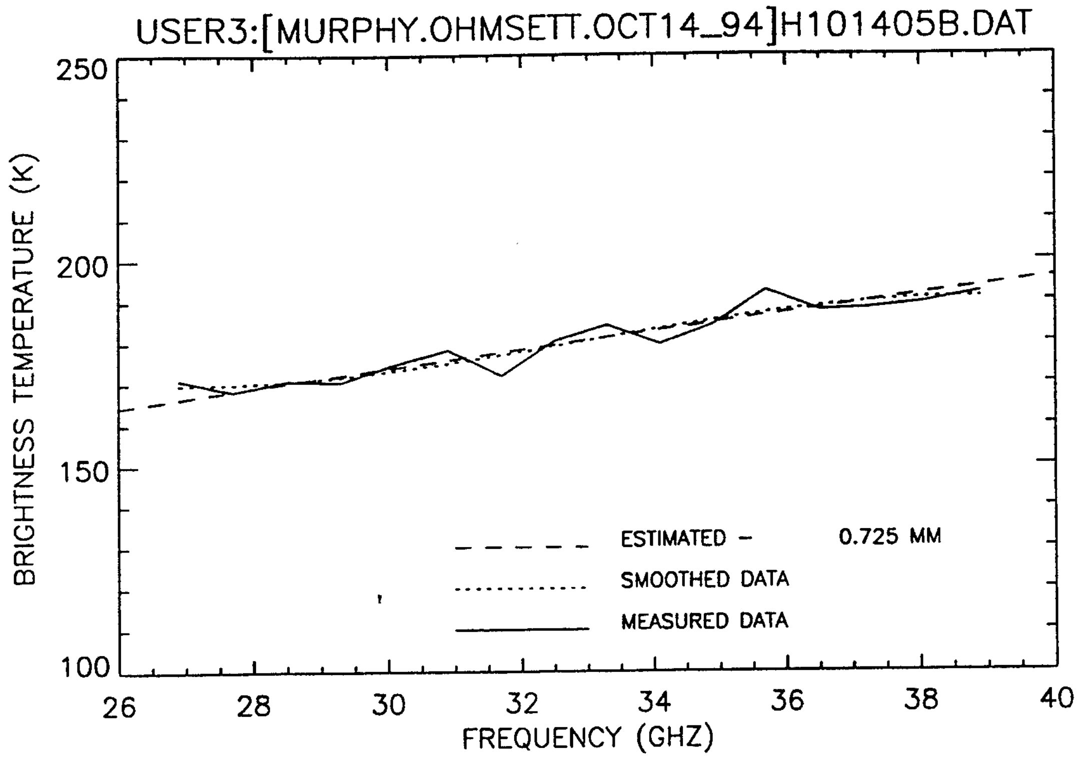

Figure D-82 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 2

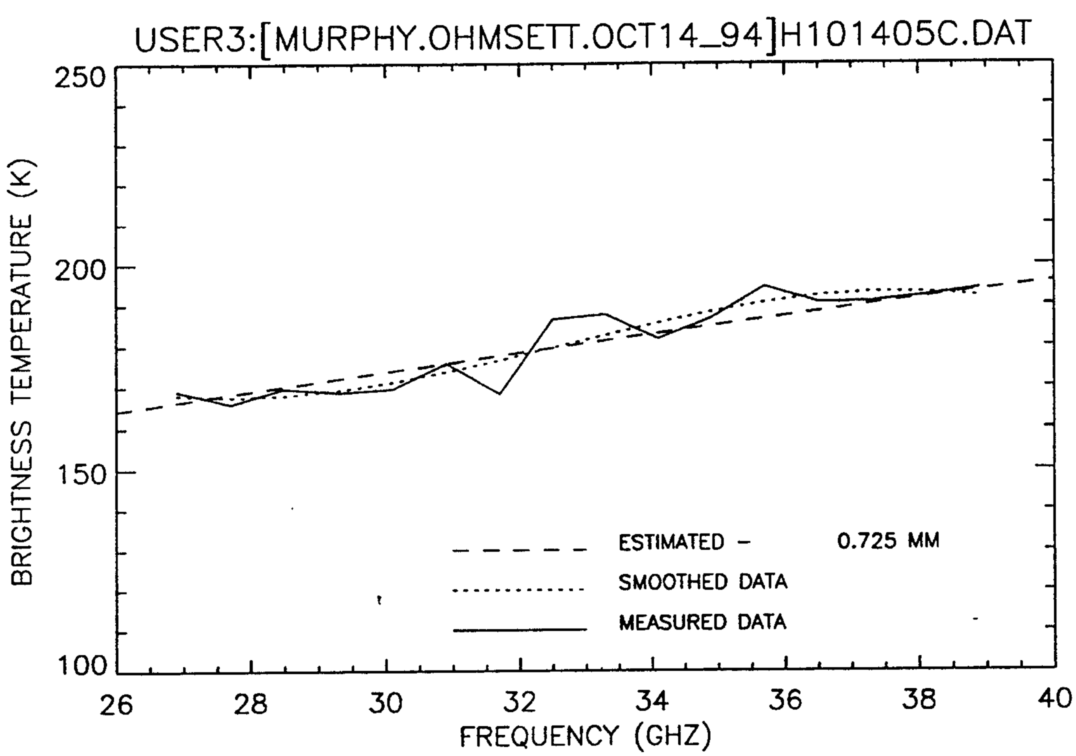

Figure D-83 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 3

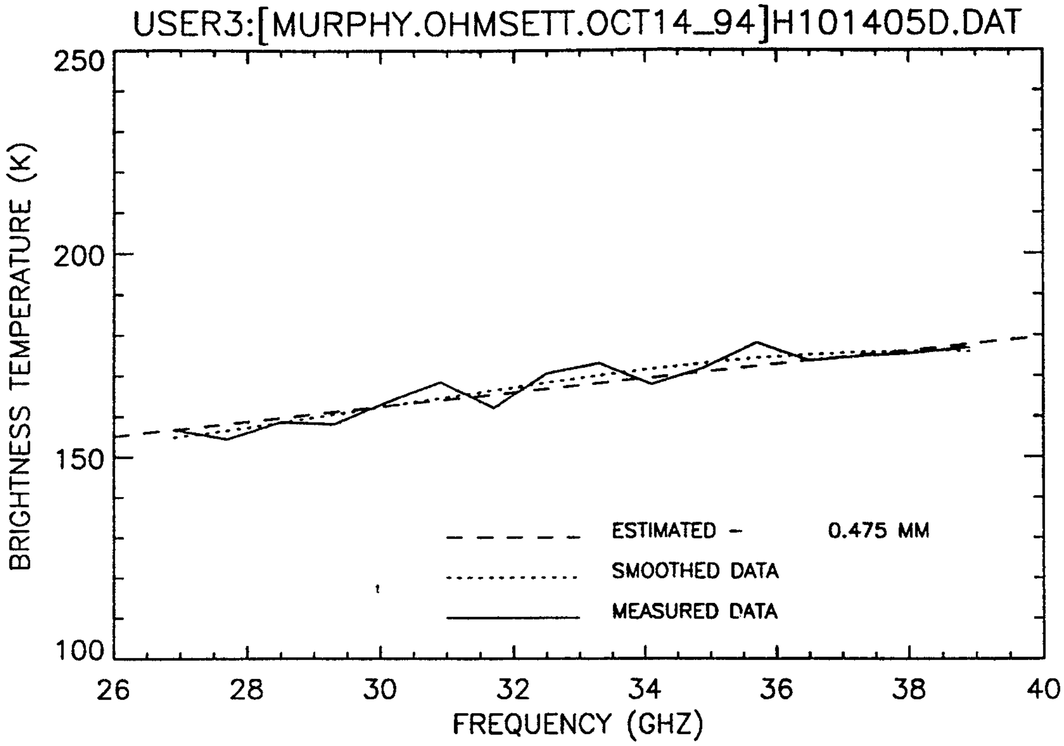

Figure D-84 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 4

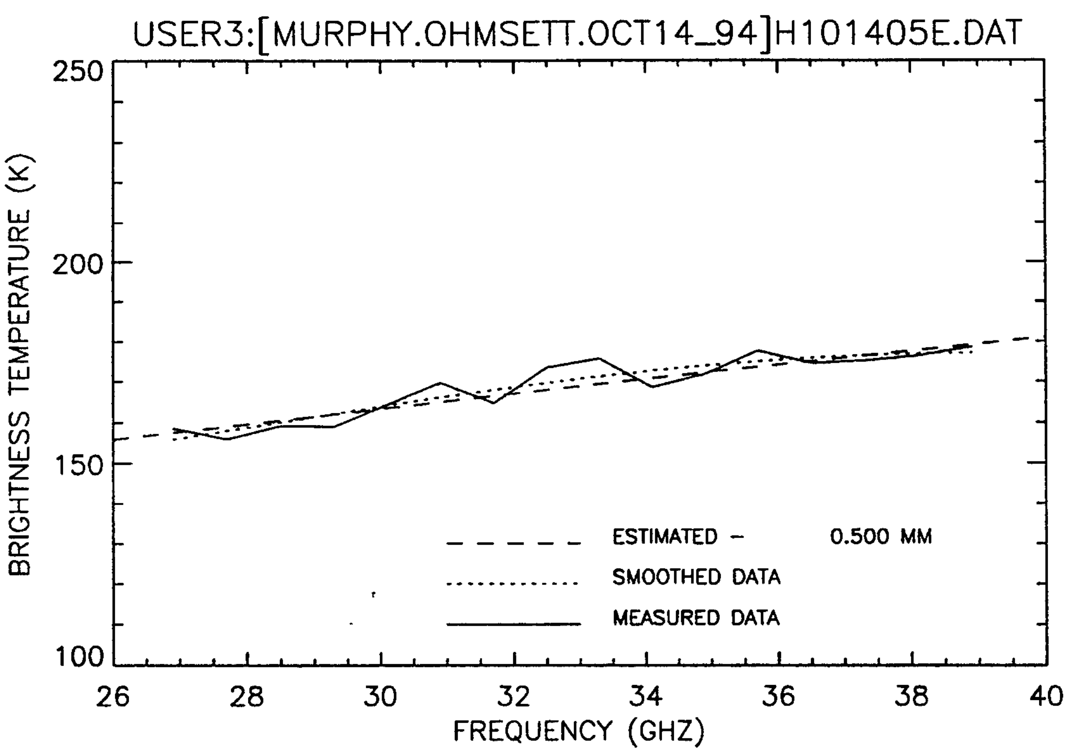

Figure D-85 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 5

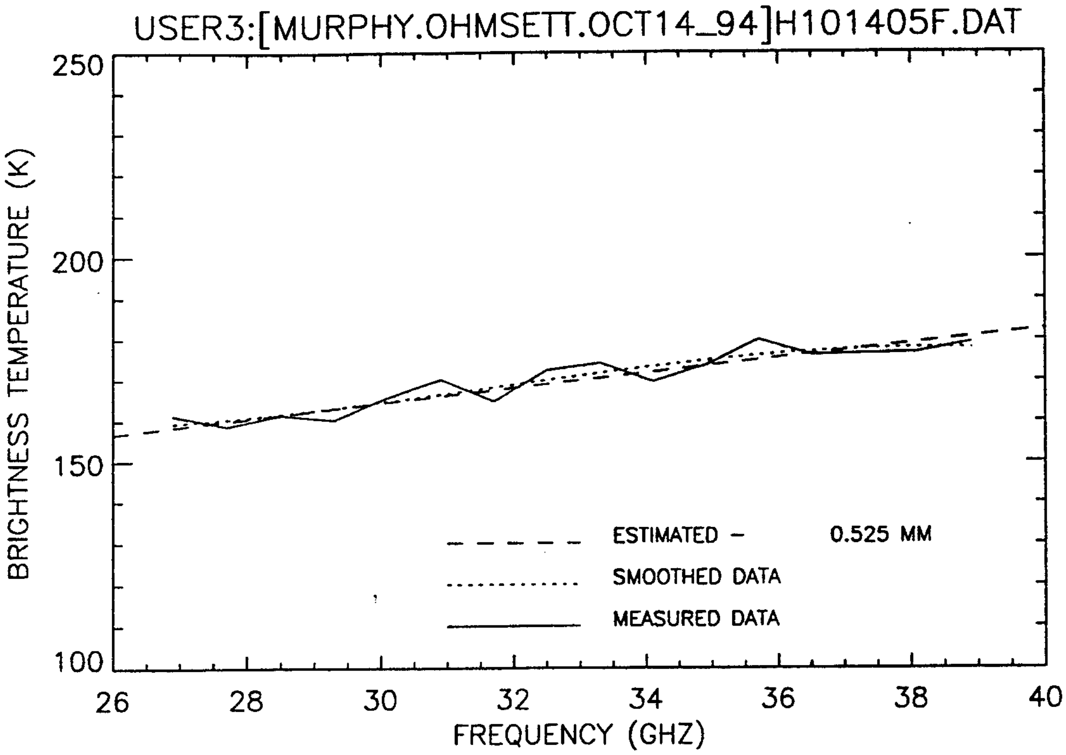

Figure D-86 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 6

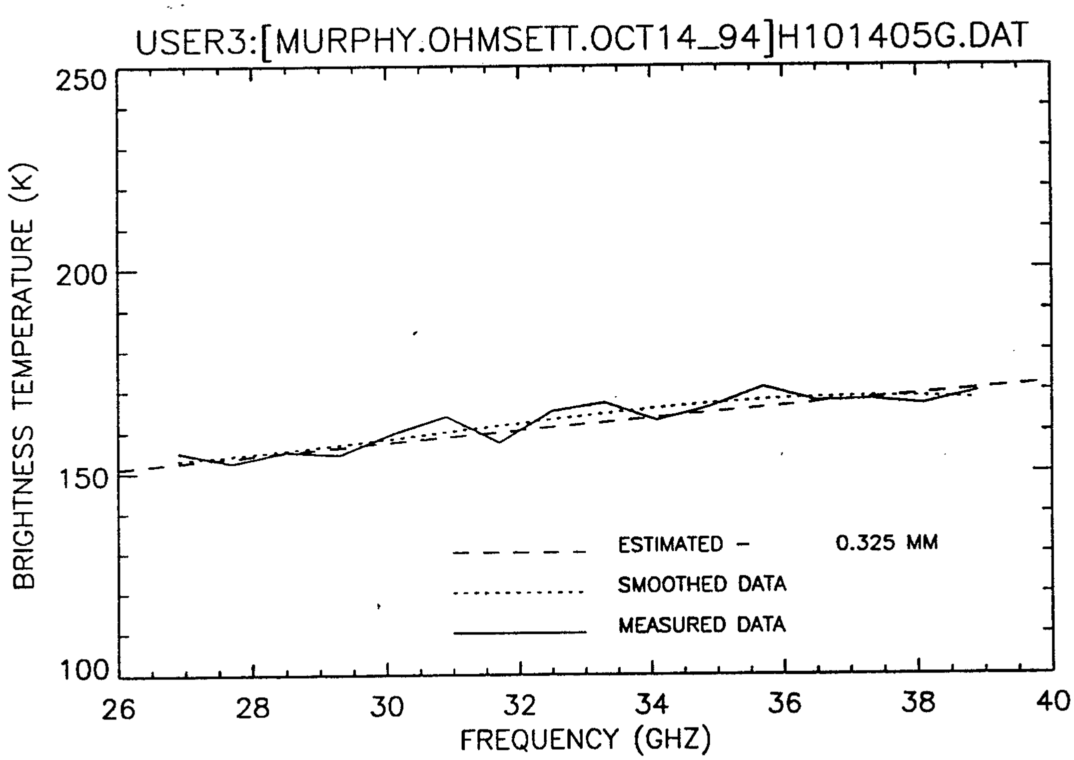

Figure D-87 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 7

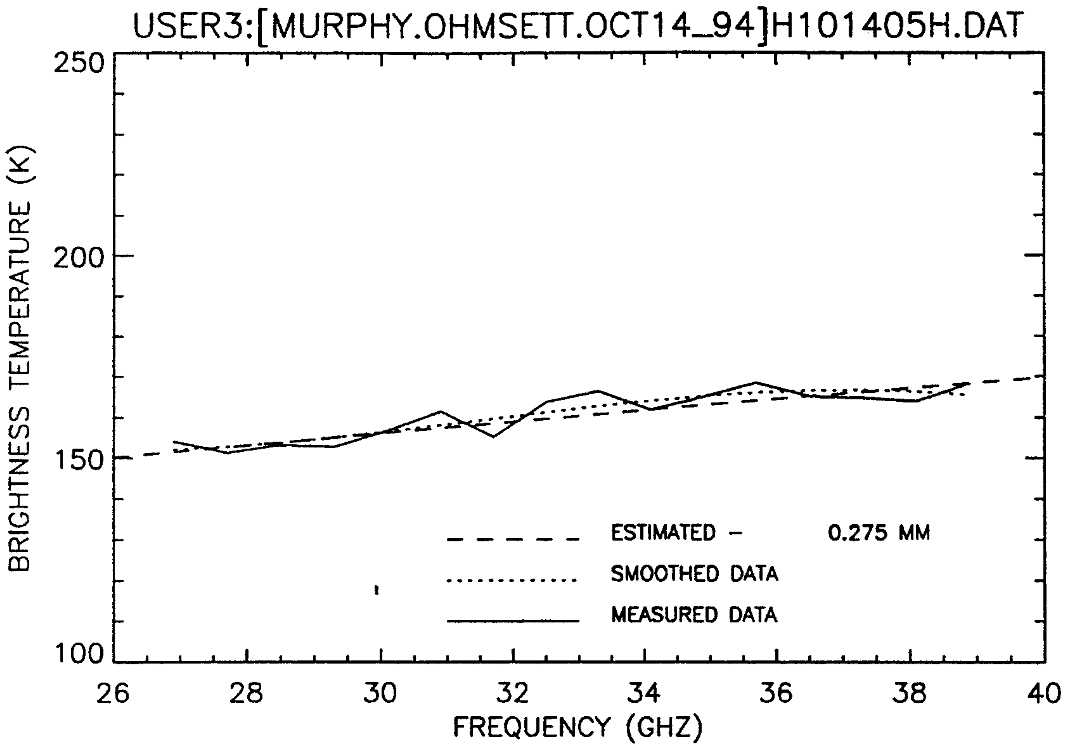

Figure D-88 T^B Versus Frequency Plot for 0.5 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 8

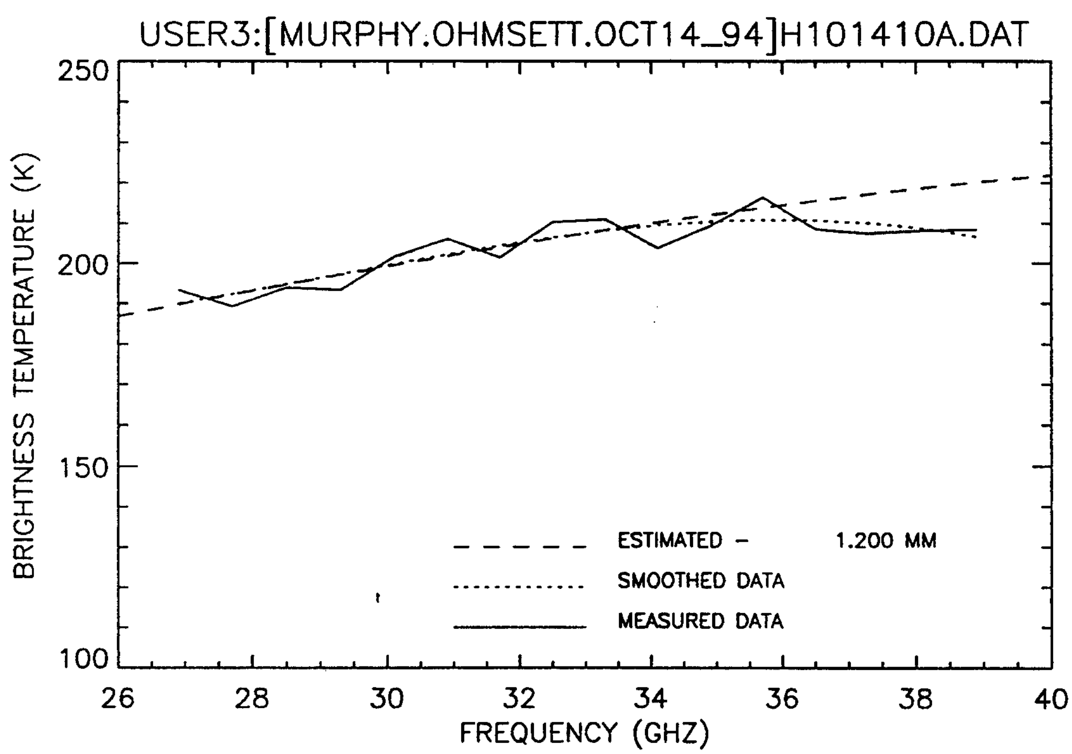

Figure D-89 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 1

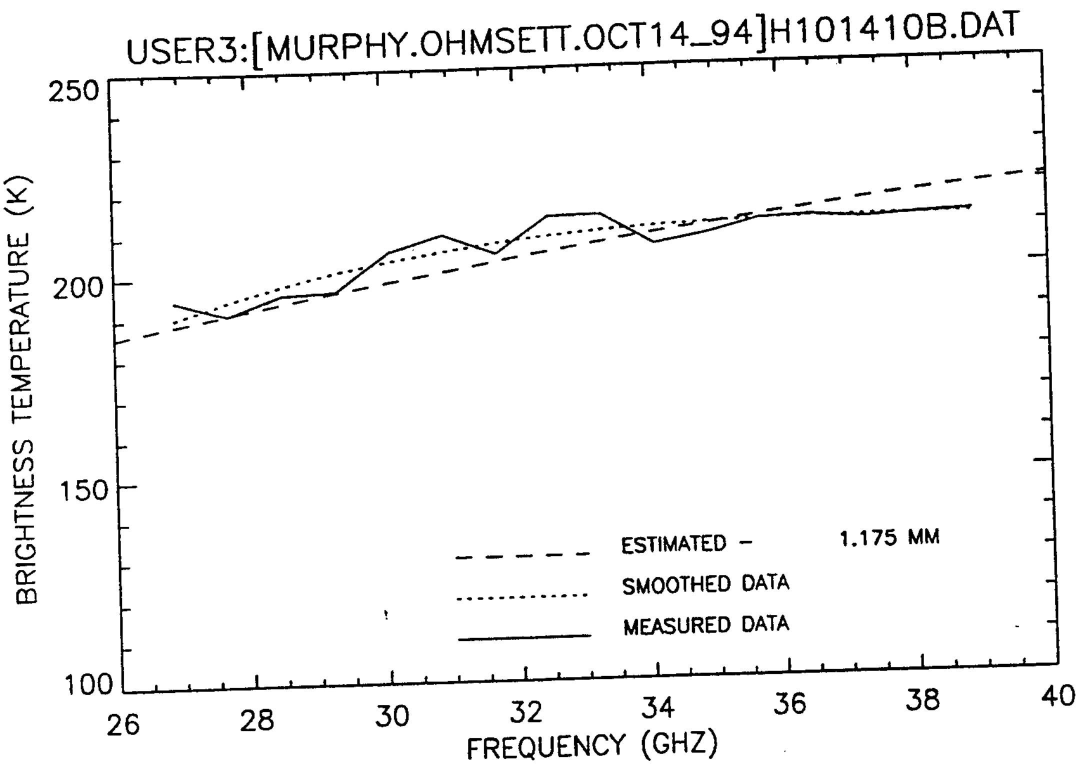

Figure D-90 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 2

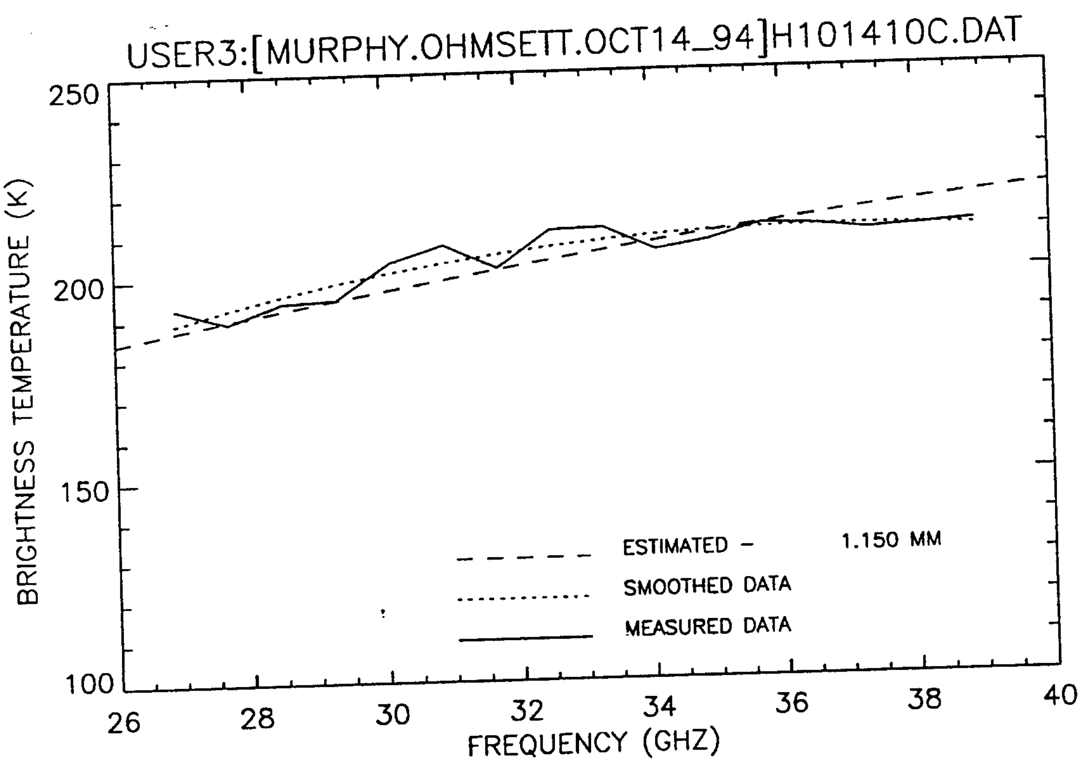

Figure D-91 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 3

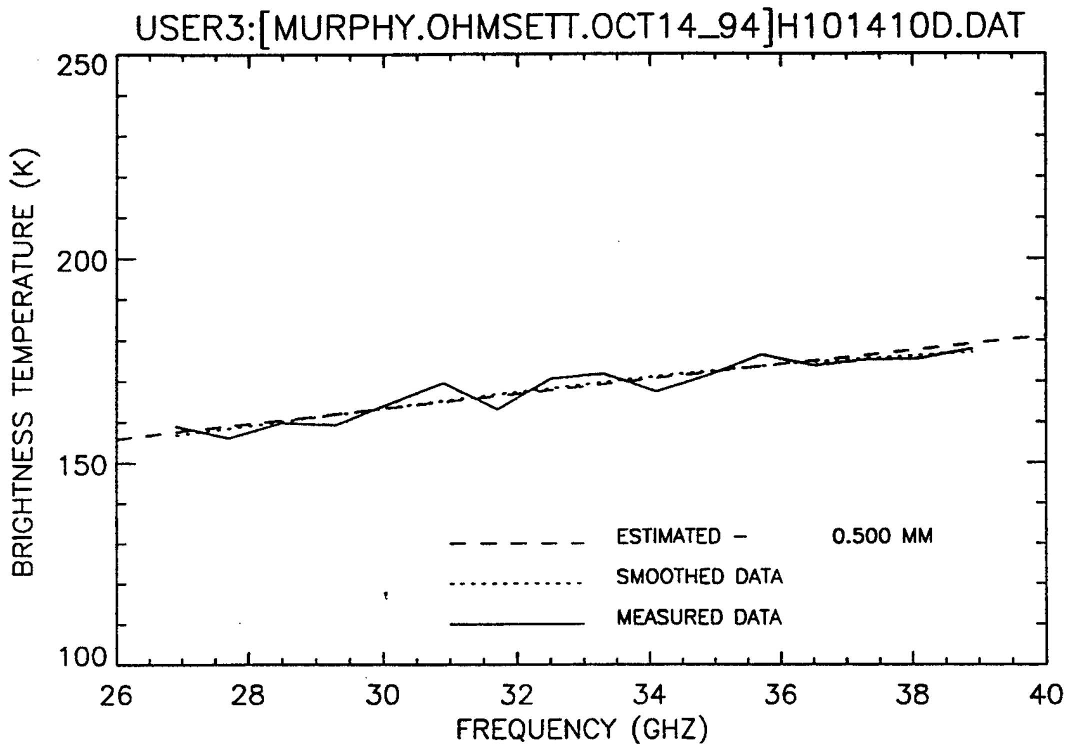

Figure D-92 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 4

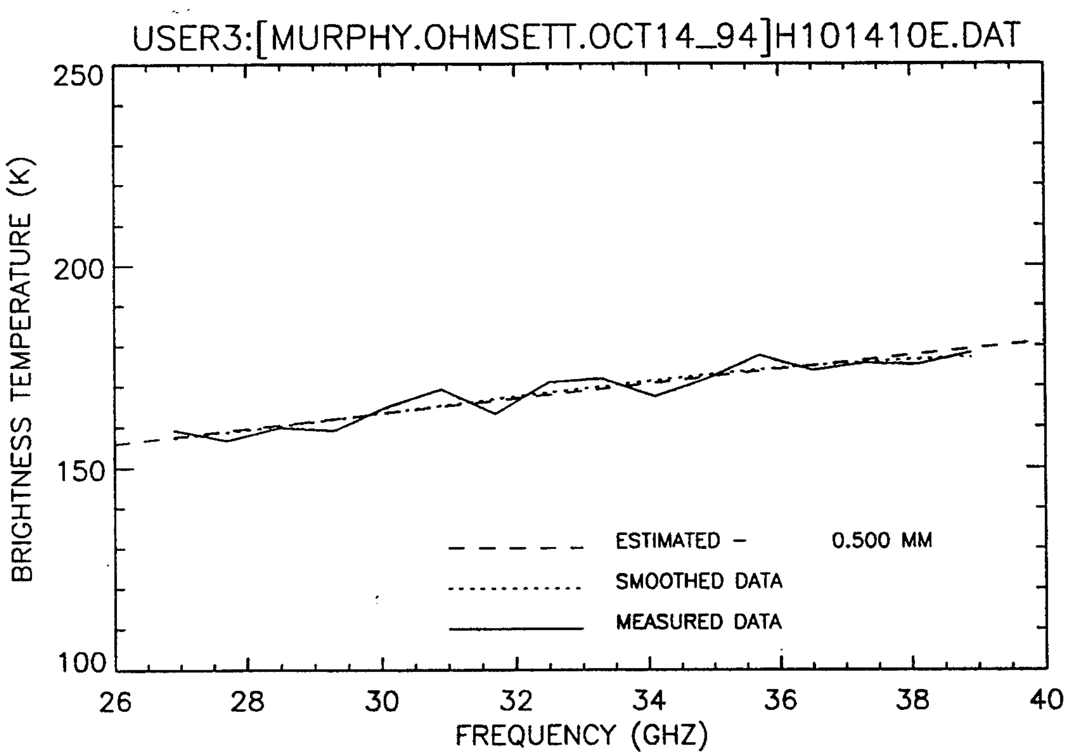

Figure D-93 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 5

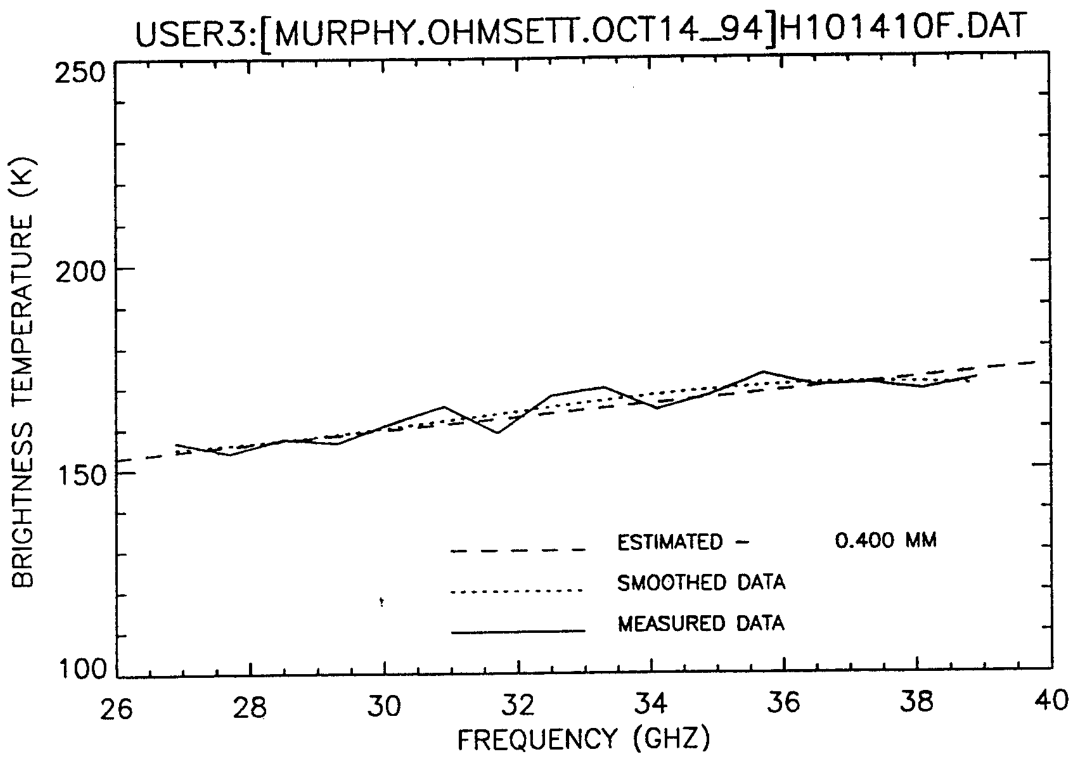

Figure D-94 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 6

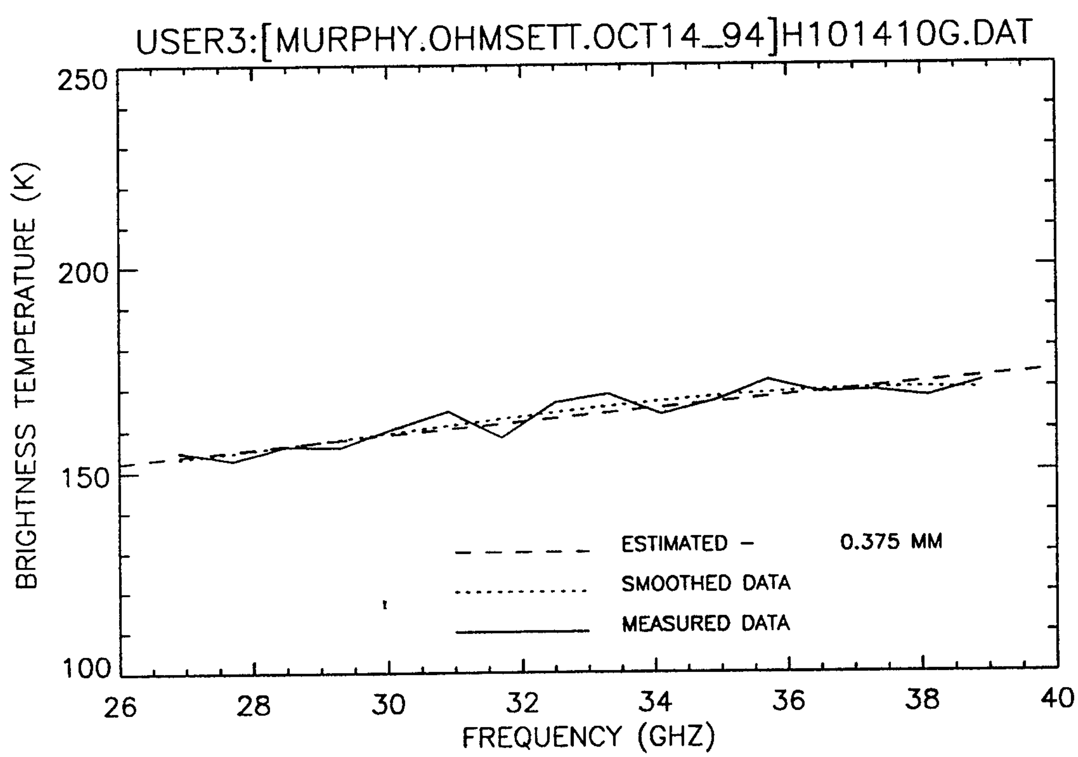

Figure D-95 T^B Versus Frequency Plot for 1.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 7

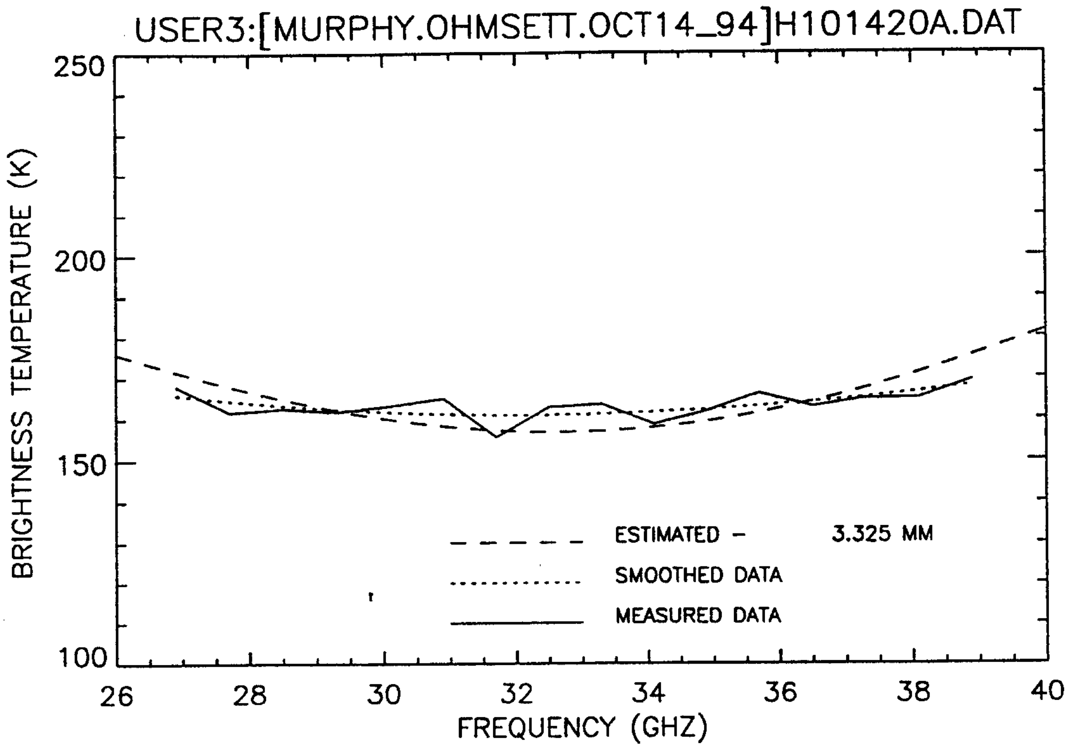

Figure D-96 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 1

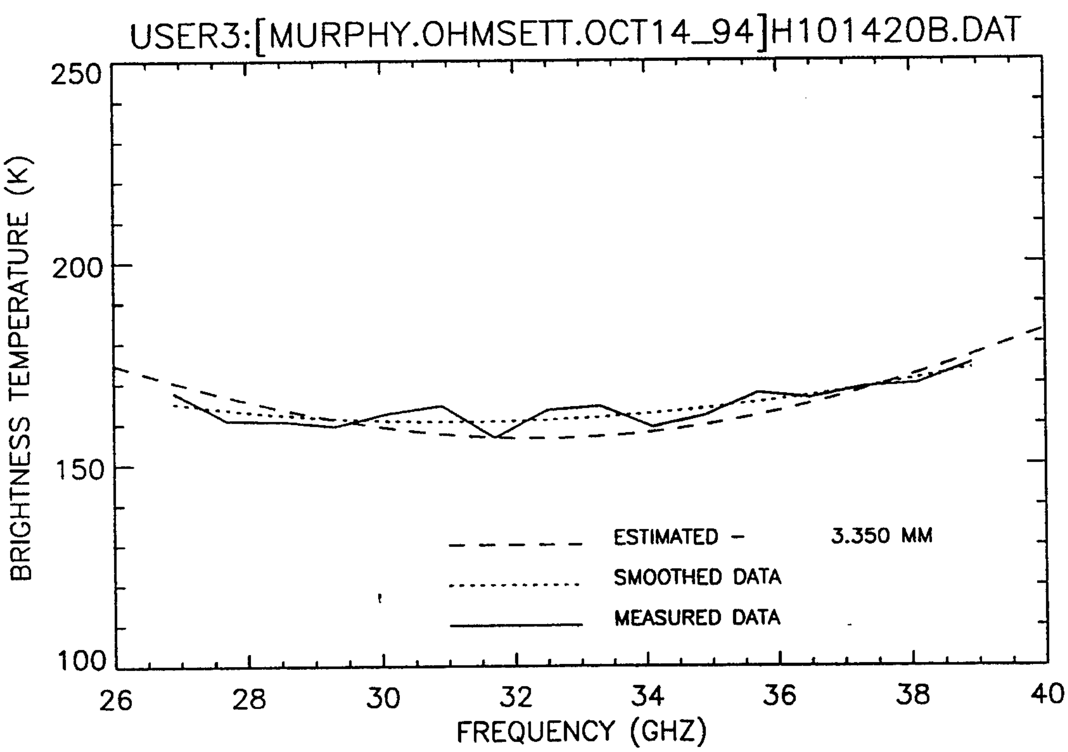

Figure D-97 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 2

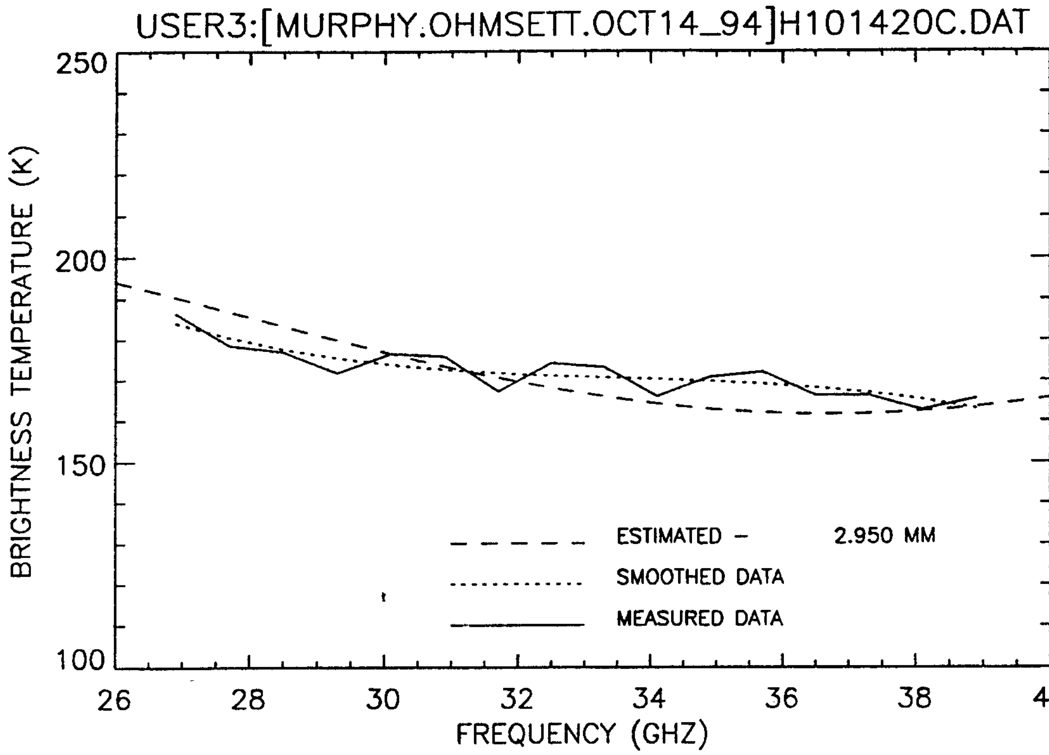

Figure D-98 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 3

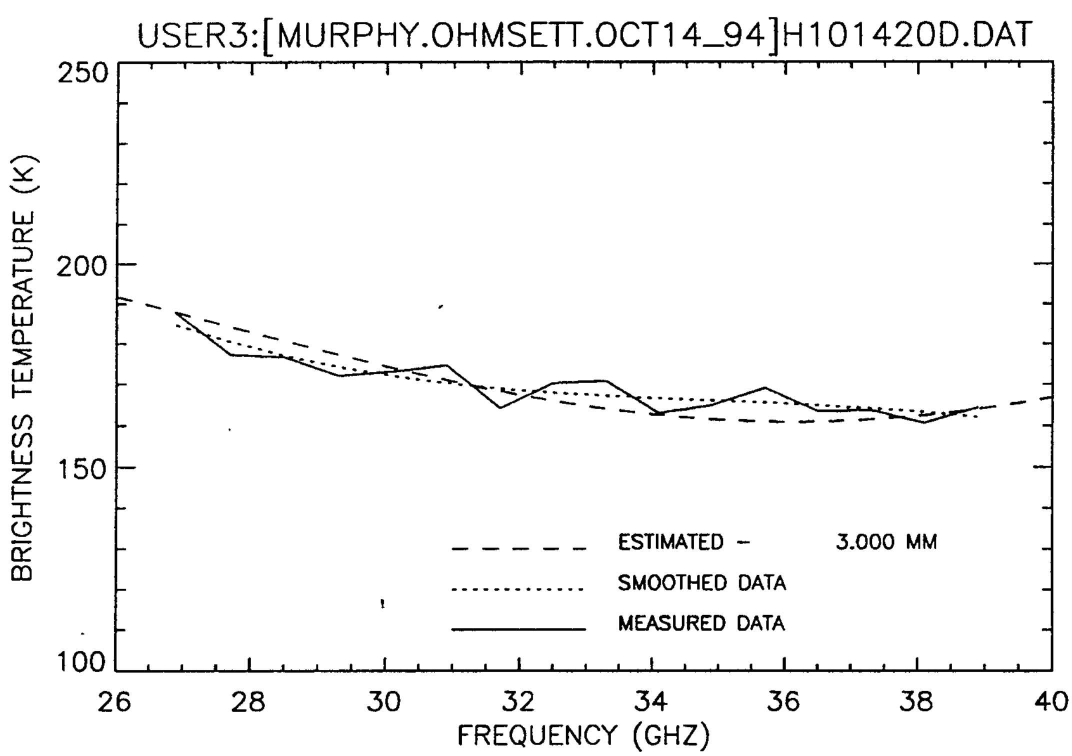

Figure D-99 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 4

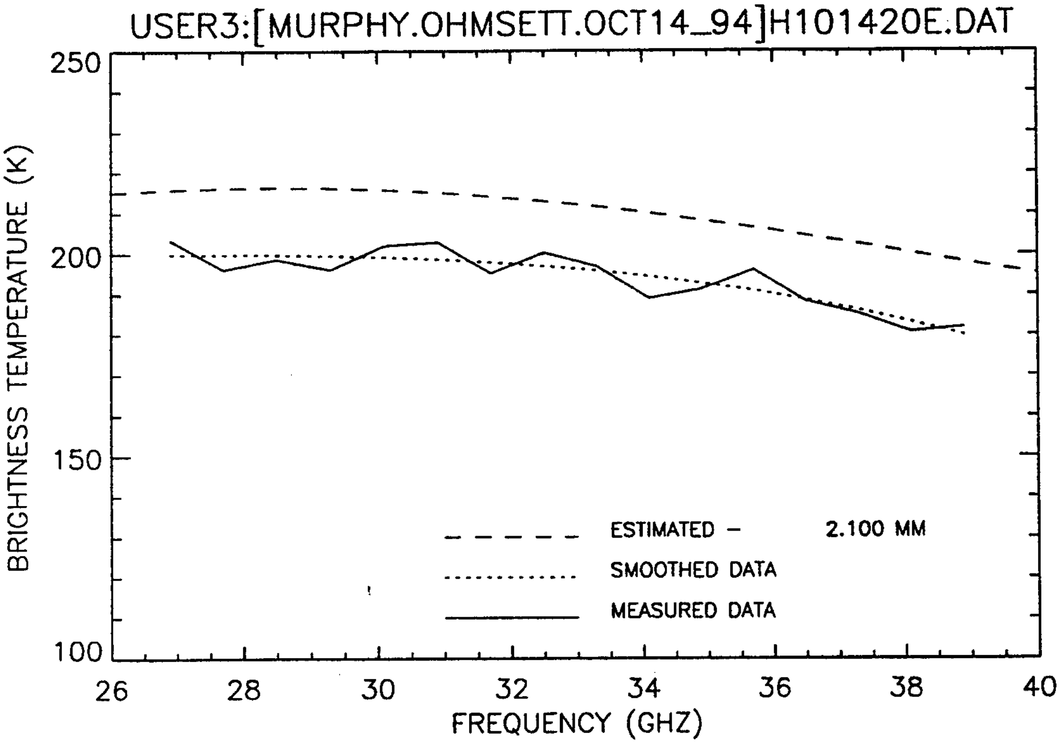

Figure D-100 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 5

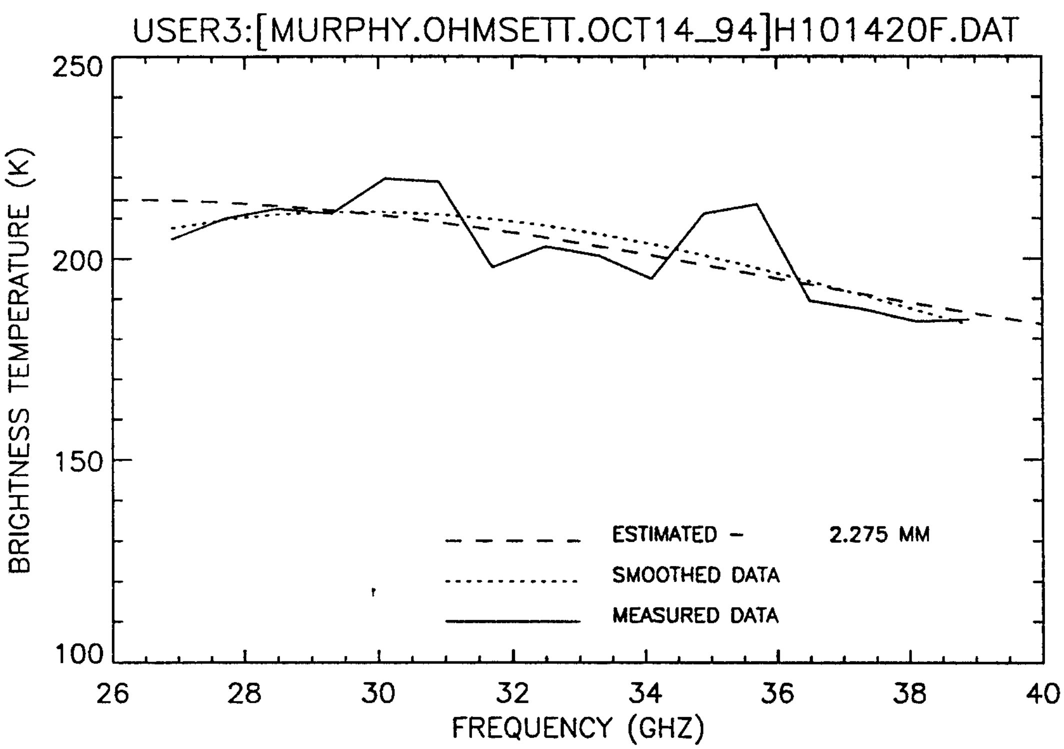

Figure D-101 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 6

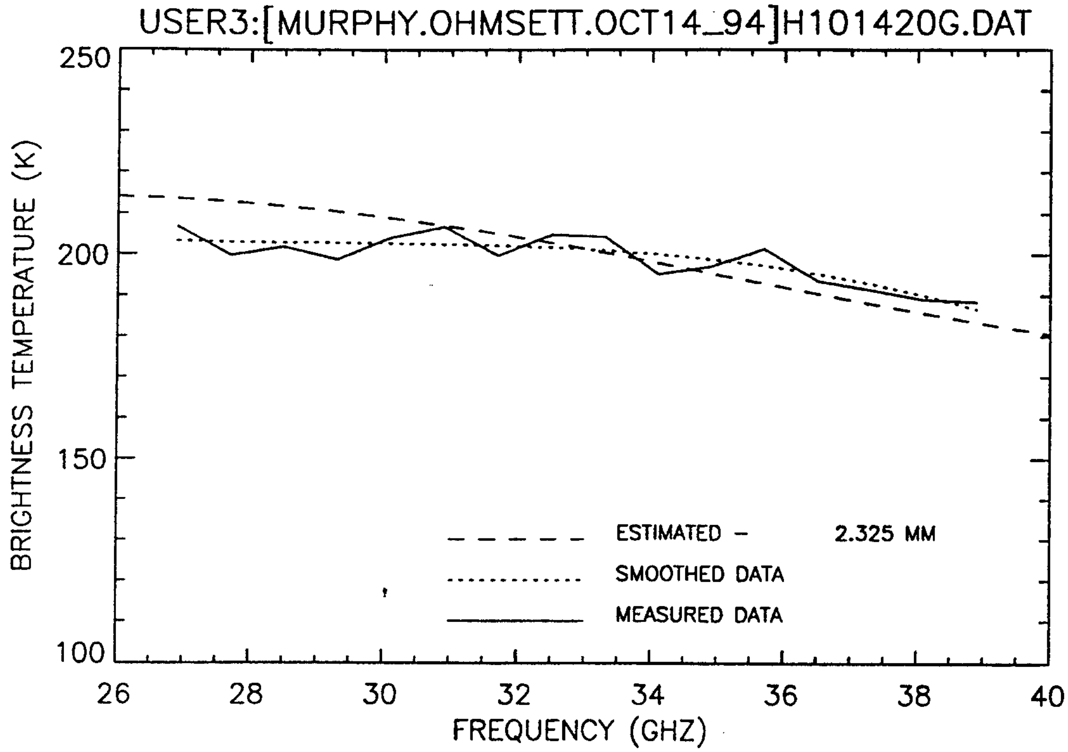

Figure D-102 T^B Versus Frequency Plot for 2.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 7

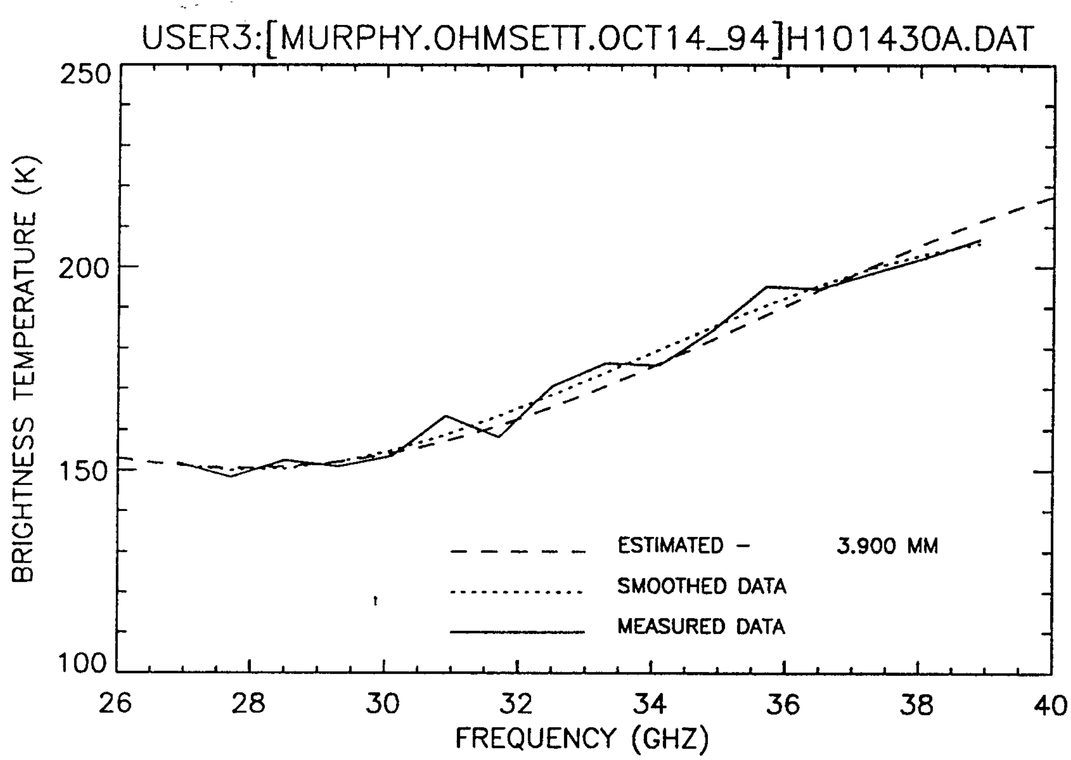

Figure D-103 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 1

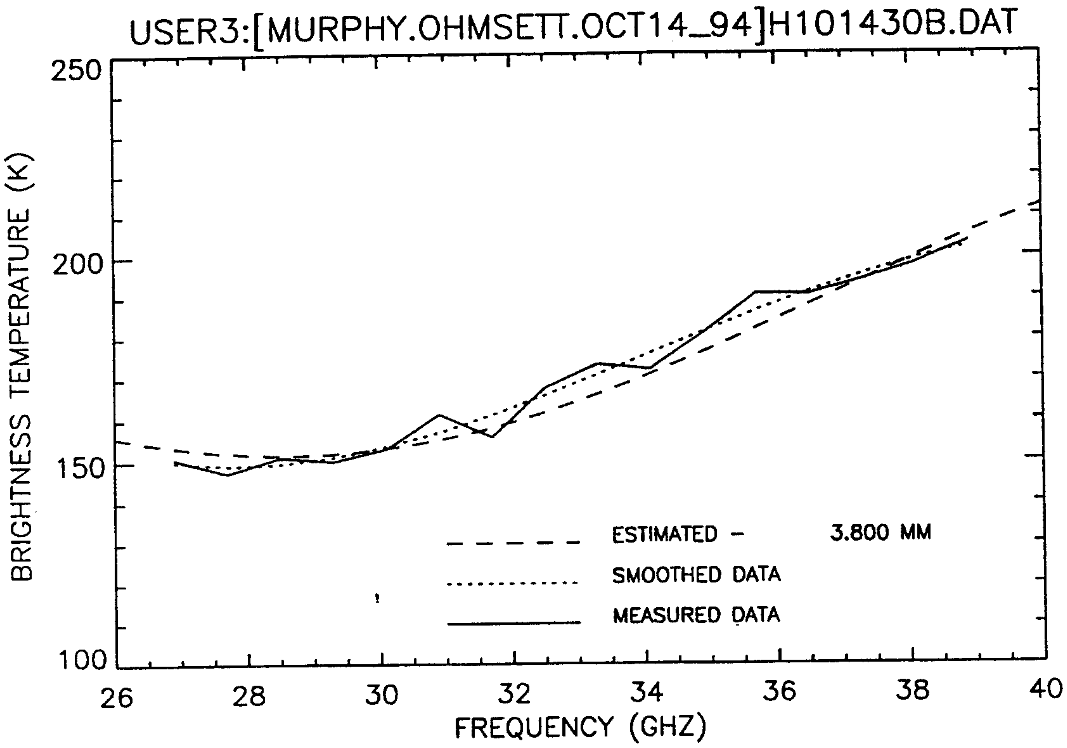

Figure D-104 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 2

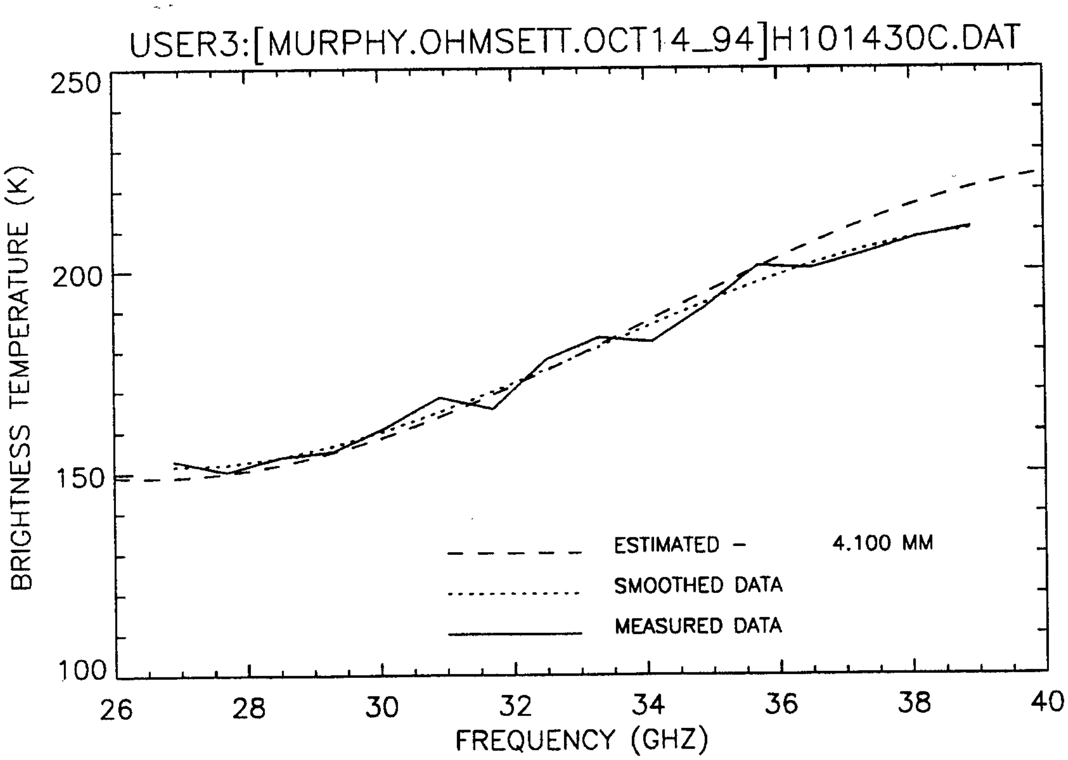

Figure D-105 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 3

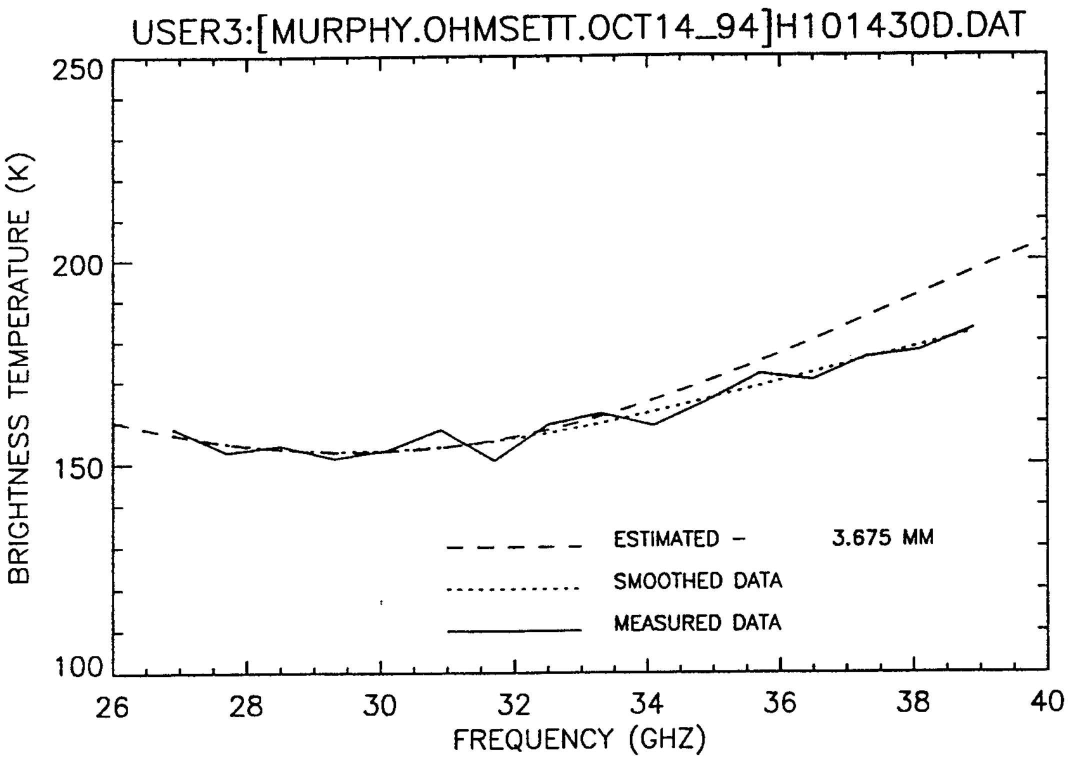

Figure D-106 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 4

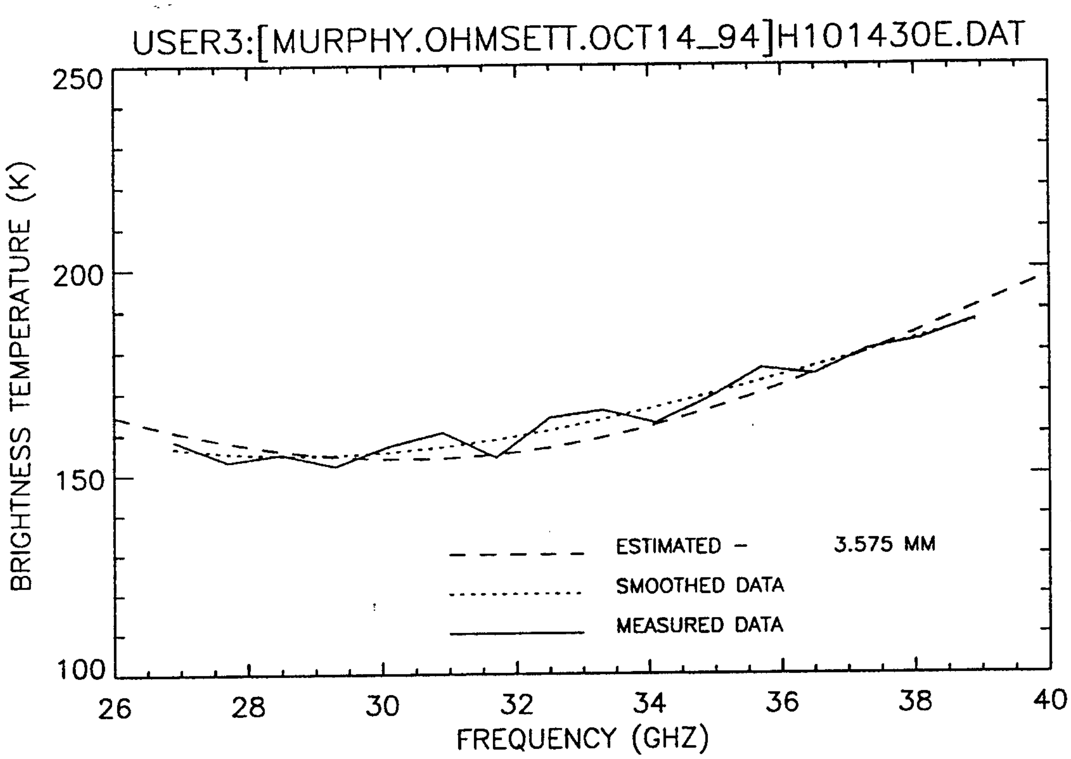

Figure D-107 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 5

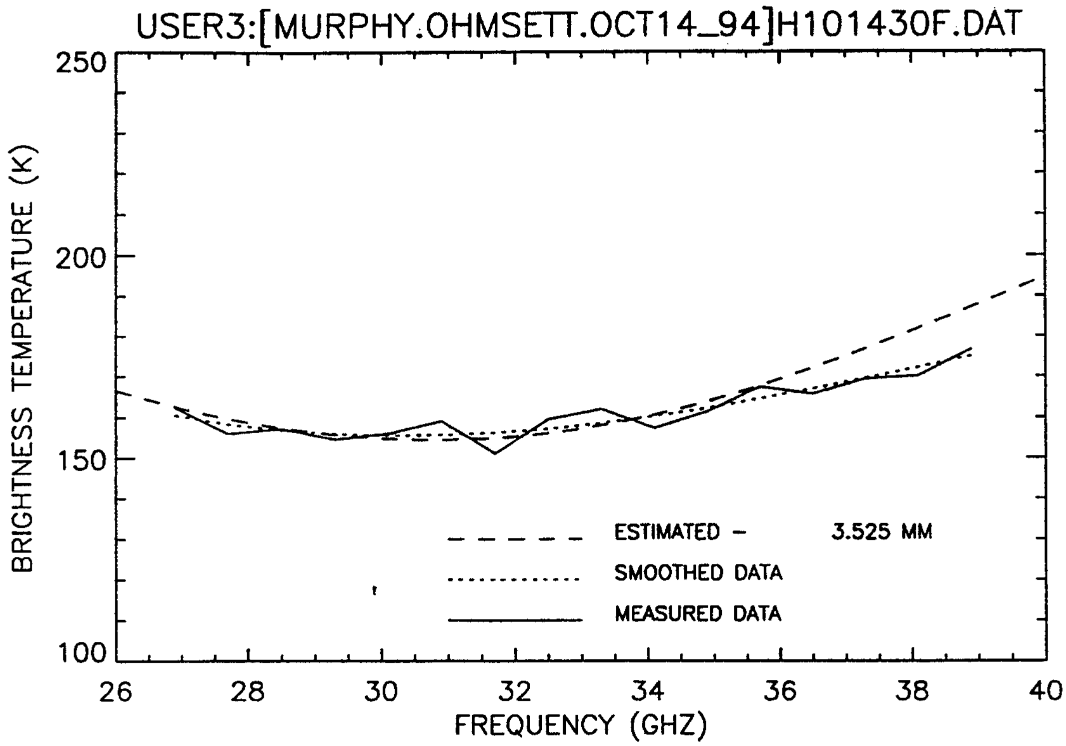

Figure D-108 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 6

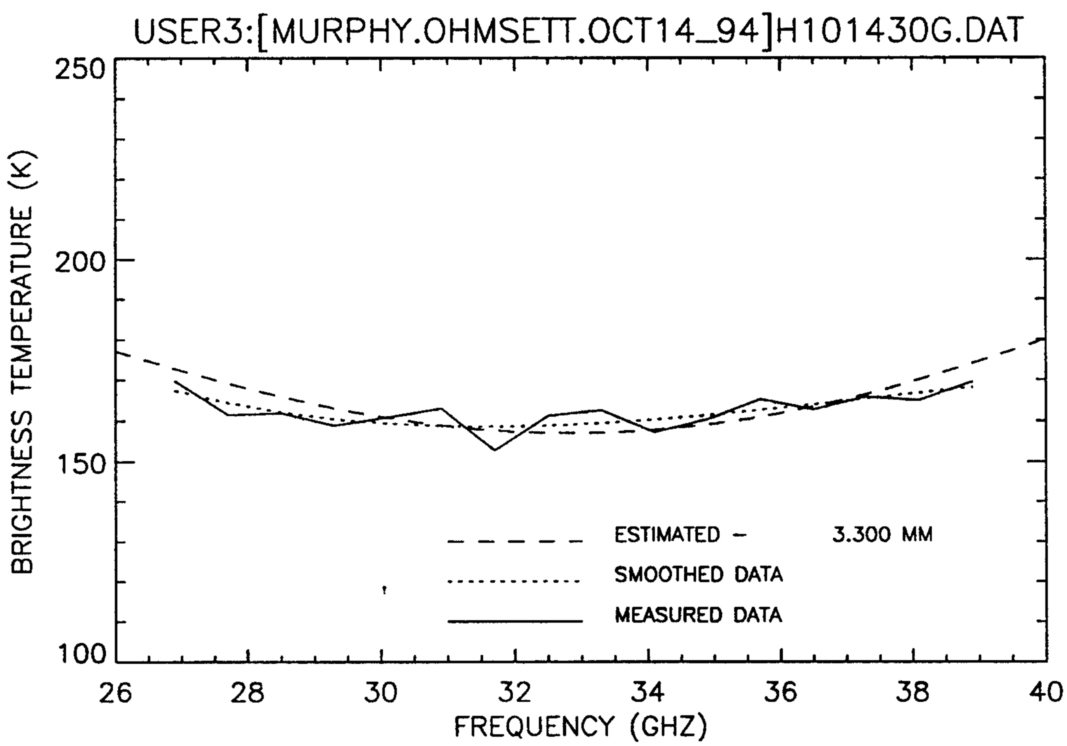

Figure D-109 T^B Versus Frequency Plot for 3.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 7

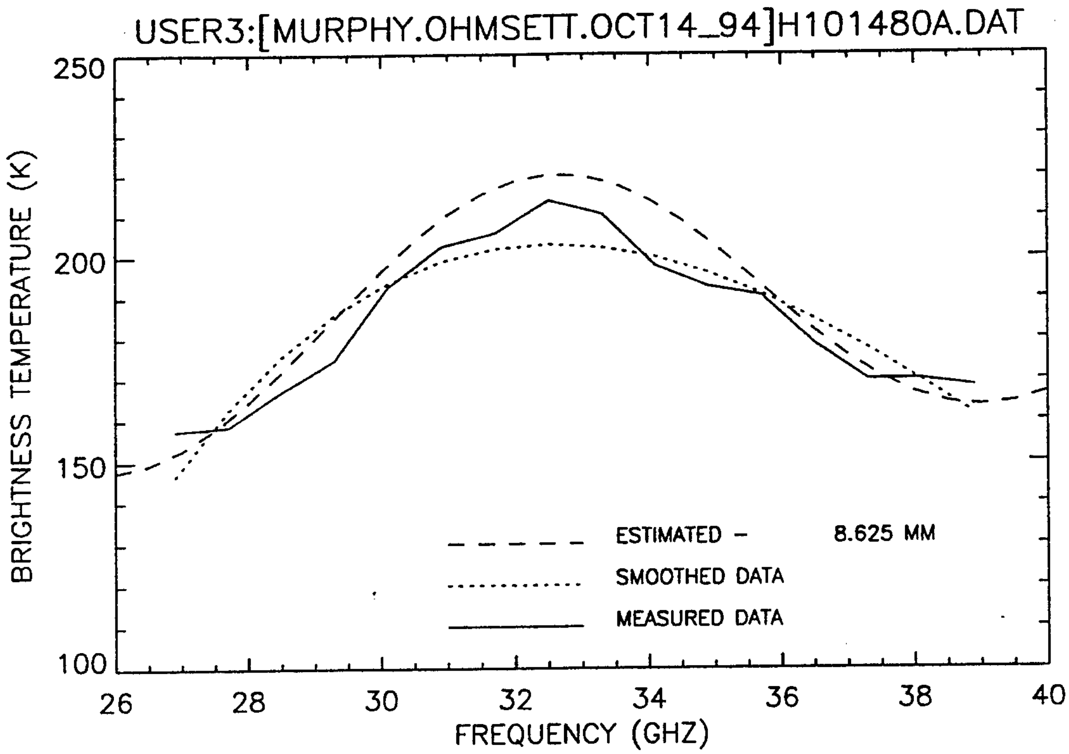

Figure D-110 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 1

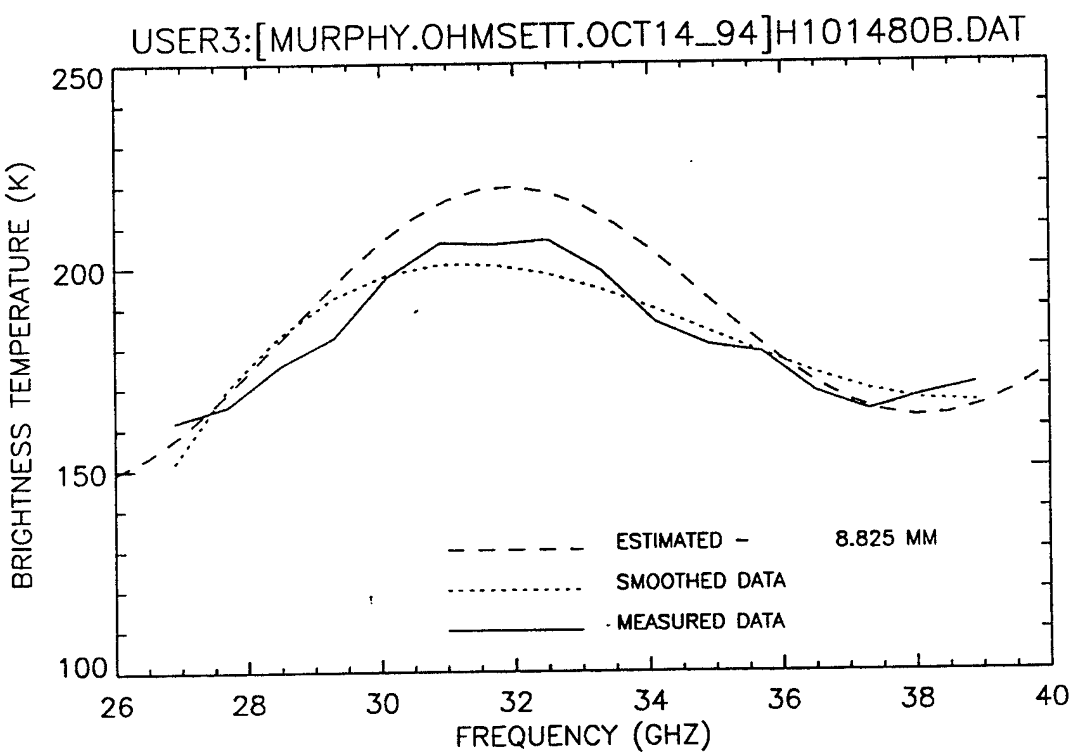

Figure D-111 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 2

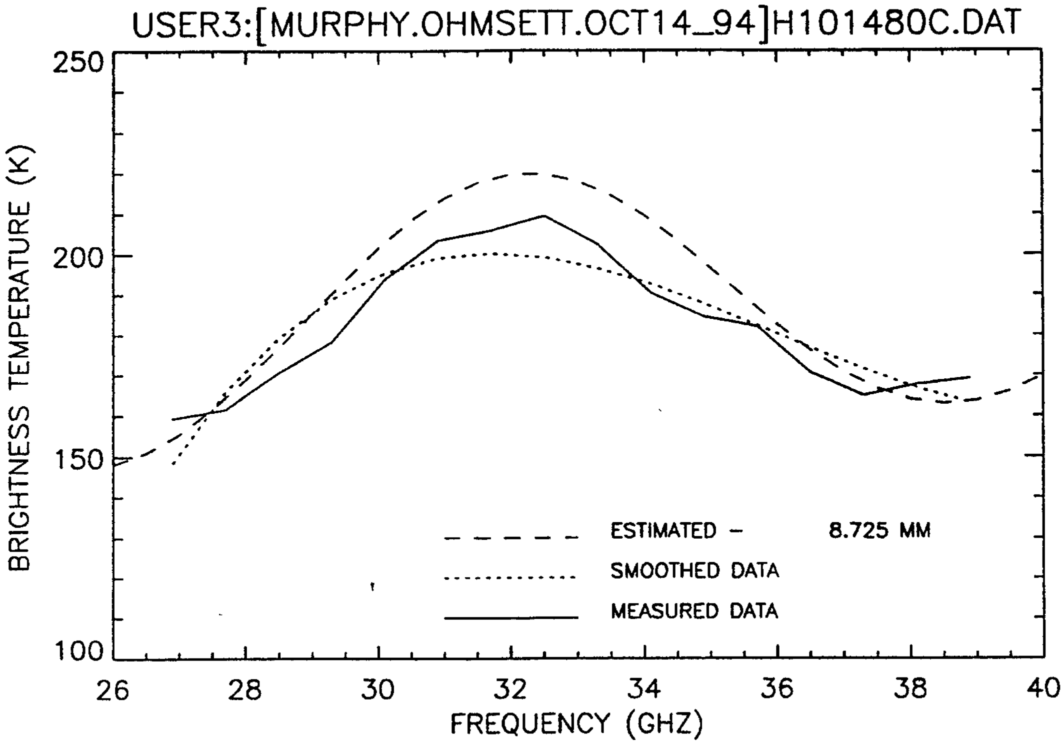

Figure D-112 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 3

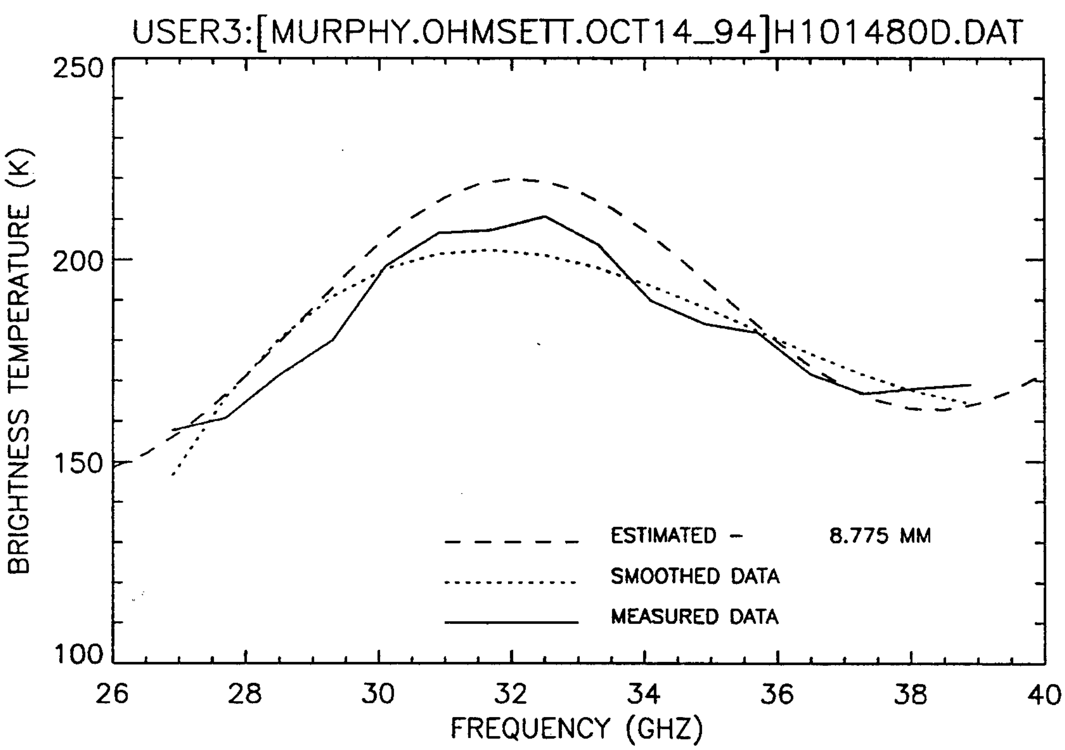

Figure D-113 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 4

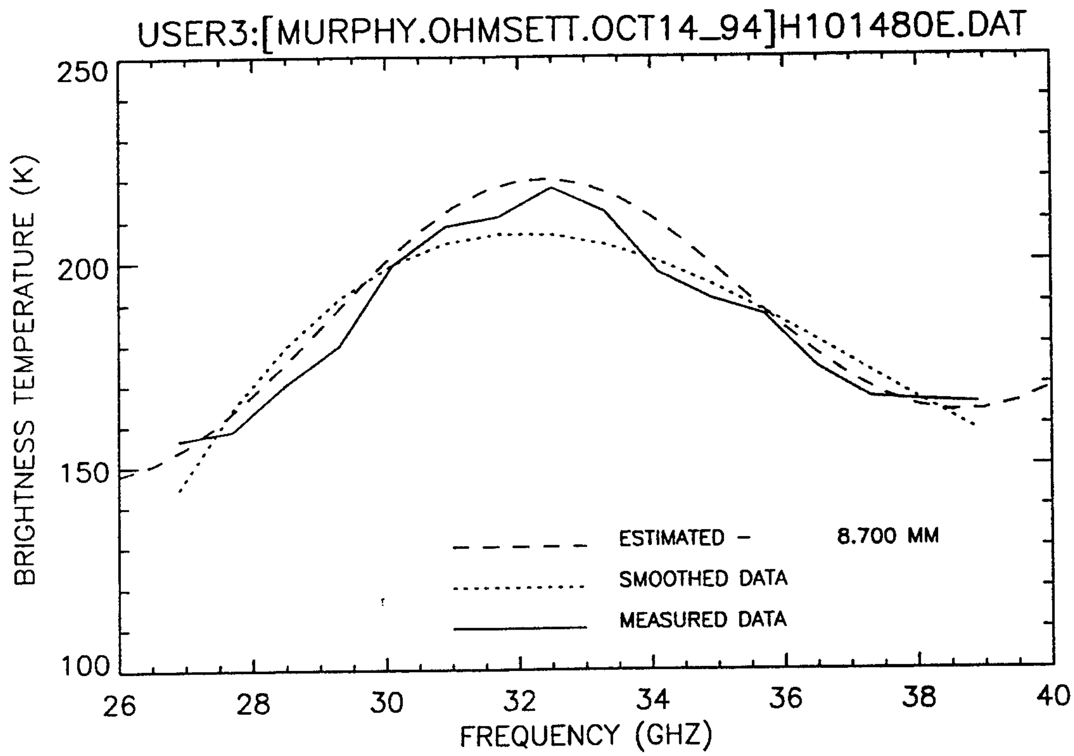

Figure D-114 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 5

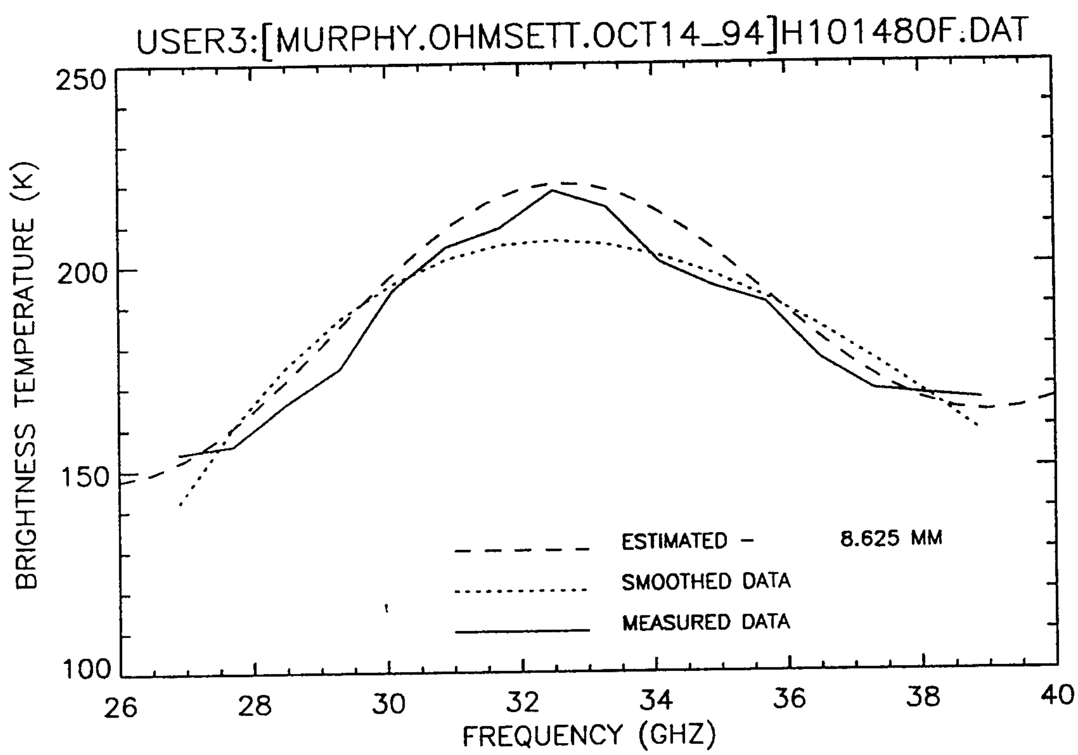

Figure D-115 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 6

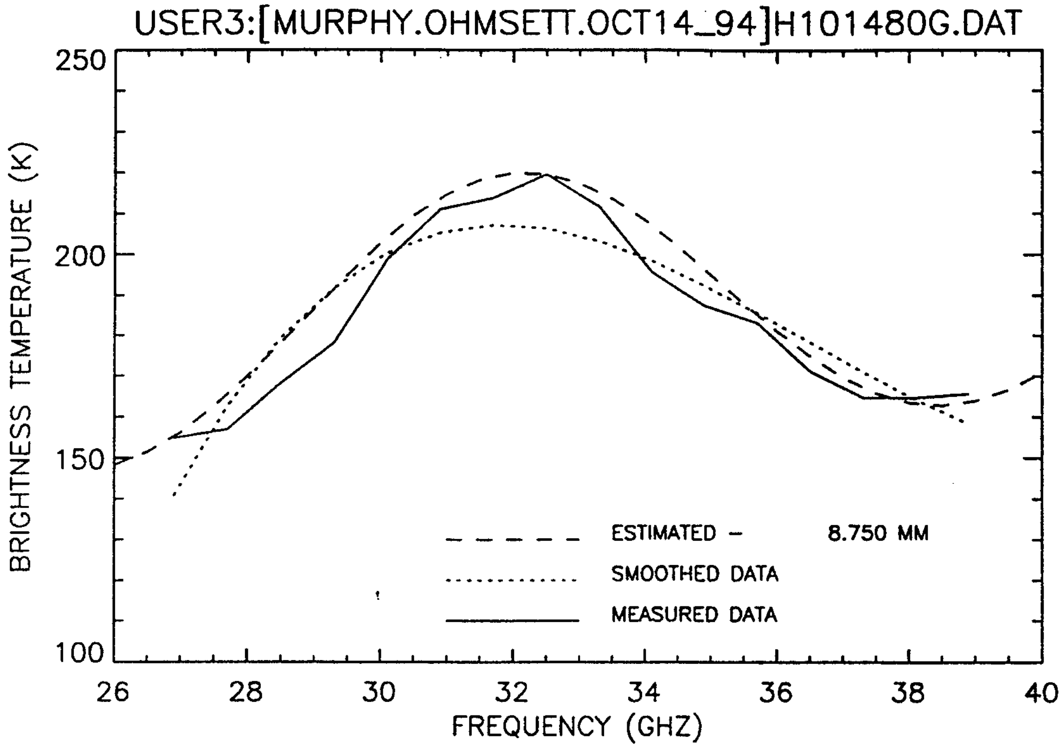

Figure D-116 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 7

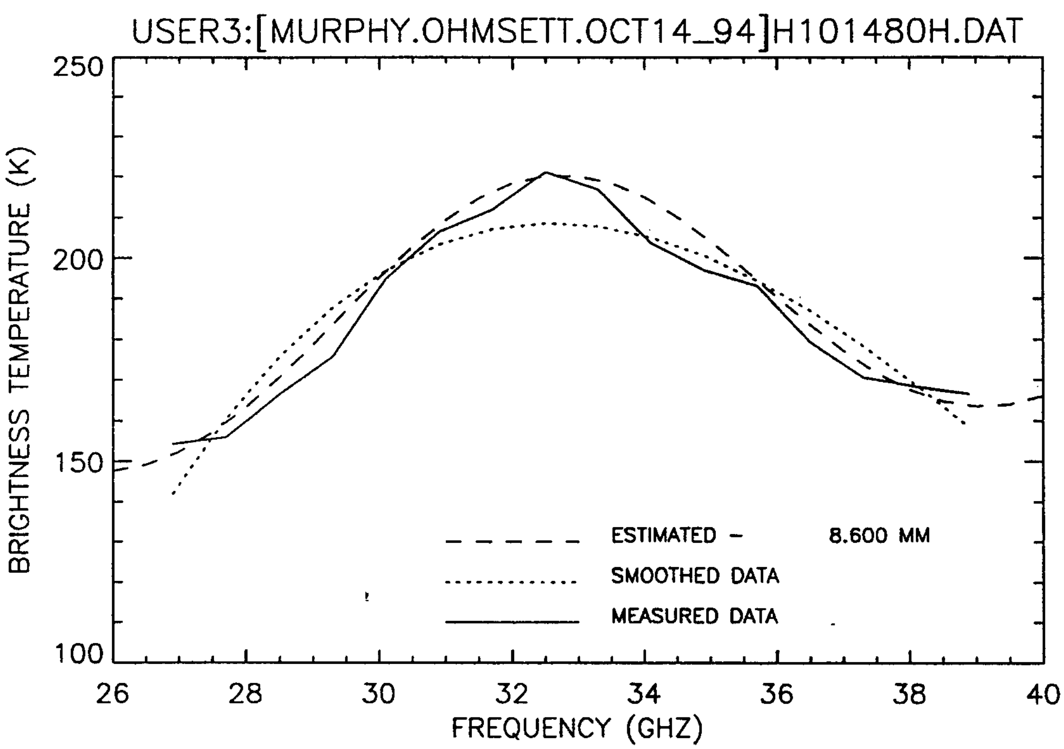

Figure D-117 T^B Versus Frequency Plot for 8.0 mm Uniform Oil Thickness, Dyed Diesel, 14 October 1994, Pass 8

Following the calm condition measurements, the wave generator was reset for a chop 1 wave condition. Some measurements on the 2.0 mm pool were collected as the chop built up and these measurements are identified below; otherwise, all measurements were performed after the wave conditions had reached steady state.

I101400A - This curve is an excellent match to the algorithm estimate of 0.000 mm.

I101400B - This curve is a good match to the algorithm estimate of 0.000 mm.

I101400C - This curve was chosen to be the water reference for this set of measurements.

The main bridge was set up over the 2.0 mm pool as the chop condition built up. The following three measurements were taken at intervals during the 20 minute wait to steady state conditions. It is interesting to note that the early measurement was inconclusive while the measurements collected under more severe wave conditions seem to match the expected oil target thickness. Earlier measurements may have experienced more sun glinting; the video images show a more subdued lighting condition with no glinting compared to the earlier measurements which had harsh, bright lighting conditions and glinting from the oil surface.

I101420A - This measurement was taken as the chop built up. The curve is a poor match to the algorithm estimate of 2.575 mm. It appears to have a shape similar to a 2.3 mm estimate (plotted), though the overall T^B seems too low. The result is inconclusive.

I101420B - This measurement was taken as the chop built up. The curve is a fair-to-good match to the algorithm estimate of 2.575 mm.

I101420C - This measurement was taken after the chop was at steady-state. The curve is a fair-to-good match to the algorithm estimate of 2.650 mm.

The following set of measurements was collected from the center of the 3.0 mm oil target pool. There were no significant features to report with respect to the oil target surface or distribution in the containment area.

I101430A - This curve is a poor match to the algorithm estimate of 0.825 mm. It appears to have a shape similar to a 4.3 mm estimate (plotted), though the overall amplitude modulation of T^B seems too low. This small modulation may be due to a partial beam fill effect of 4.3 mm thick oil. The result is inconclusive.

I101430B - This curve is a fair match to the algorithm estimate of 0.900 mm.

I101430C - This curve is a fair-to-good match to the algorithm estimate of 1.100 mm.

I101430D - This curve is a fair match to the algorithm estimate of 1.075 mm.

I101430E - This curve is a poor match to the algorithm estimate of 1.650 mm. Because of the high T^B response, it was likely caused by emulsion or bubbles on the surface. The data curve roll-off after 36 GHz is similar in shape to a 4.7 mm estimate (plotted), but, as the plot illustrates, the match is very poor.

The following measurements were collected from the center of the 8.0 mm oil target pool. Some bubbles were observed on the oil target surface.

I101480A - This curve is a poor match to the algorithm estimate of 0.825 mm. It has a shape similar to a 4.8 mm estimate (plotted), though there is insufficient amplitude modulation to match the estimate. It does not exhibit a sinusoidal shape similar to an 8.0 mm prediction. The result is inconclusive.

I101480B - This curve is a poor match to the algorithm estimate of 0.850 mm. It does not exhibit a sinusoidal shape similar to an 8.0 mm prediction. The result is inconclusive.

I101480C - This curve is a poor match to the algorithm estimate of 0.875 mm. It does seem to exhibit a sinusoidal shape similar to an 8.9 mm prediction (plotted), however, the amplitude modulation is much too low. The result is inconclusive.

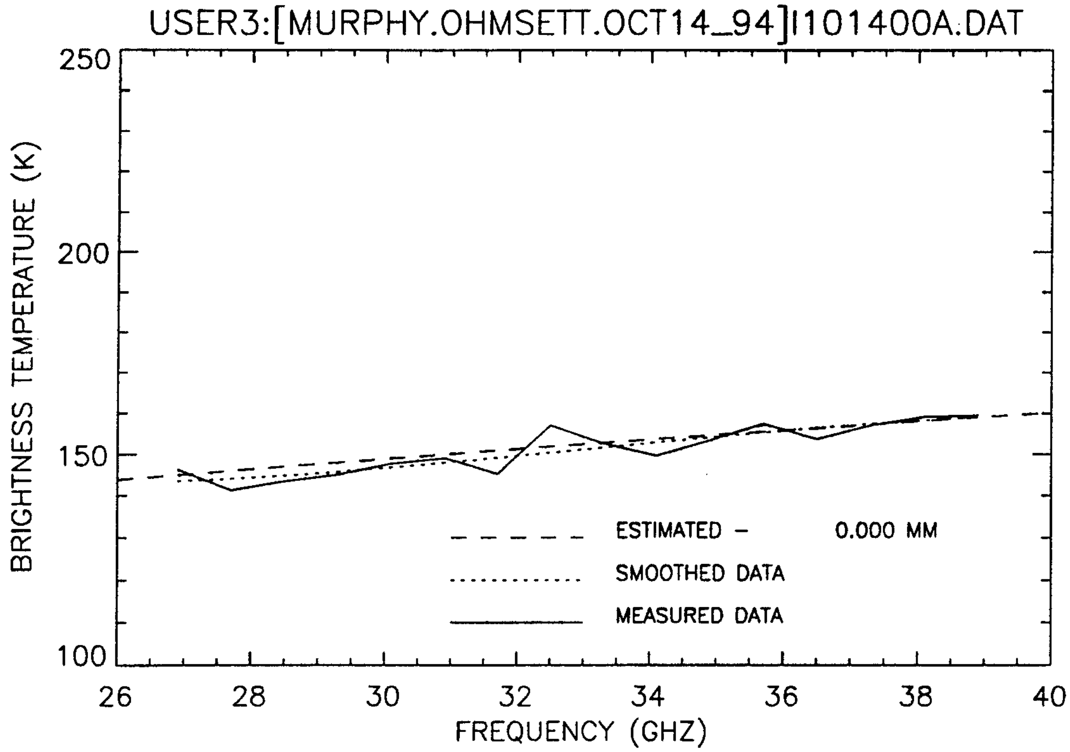

Figure D-118 T^B Versus Frequency Plot for Background Water, Chop Condition 1, 14 October 1994, Pass 1

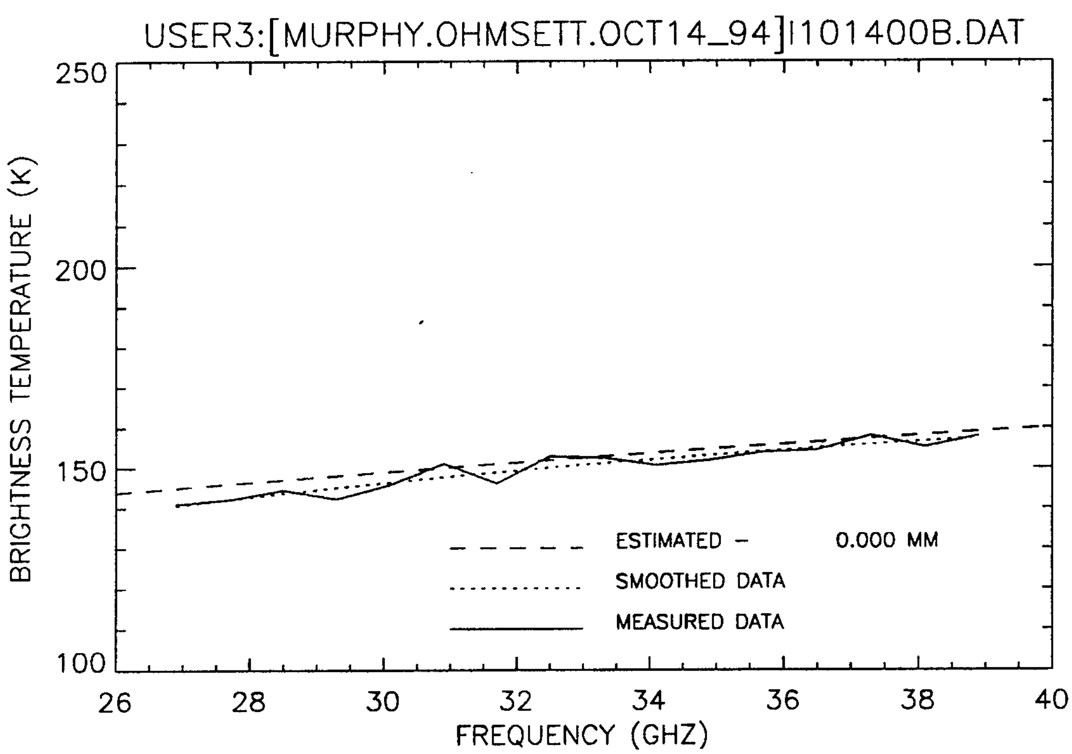

Figure D-119 T^B Versus Frequency Plot for Background Water, Chop Condition 1, 14 October 1994, Pass 2

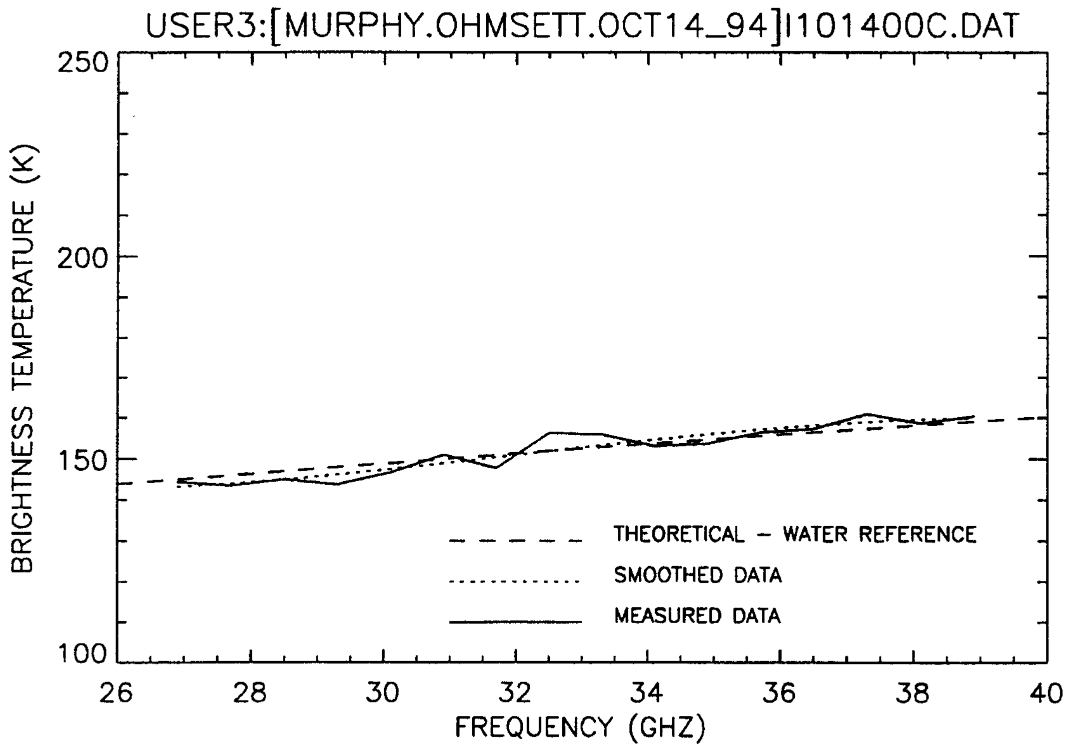

Figure D-120 T^B Versus Frequency Plot for Background Water, Chop Condition 1, 14 October 1994, Pass 3

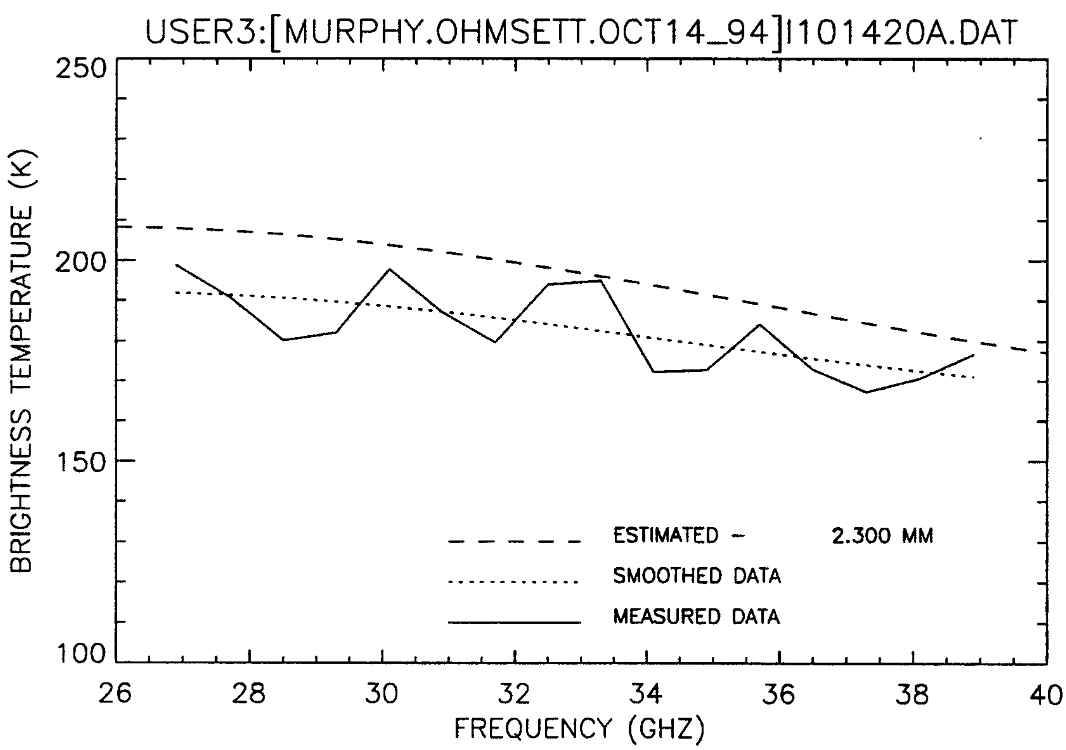

Figure D-121 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Chop Condition 1, 14 October 1994, Pass 1

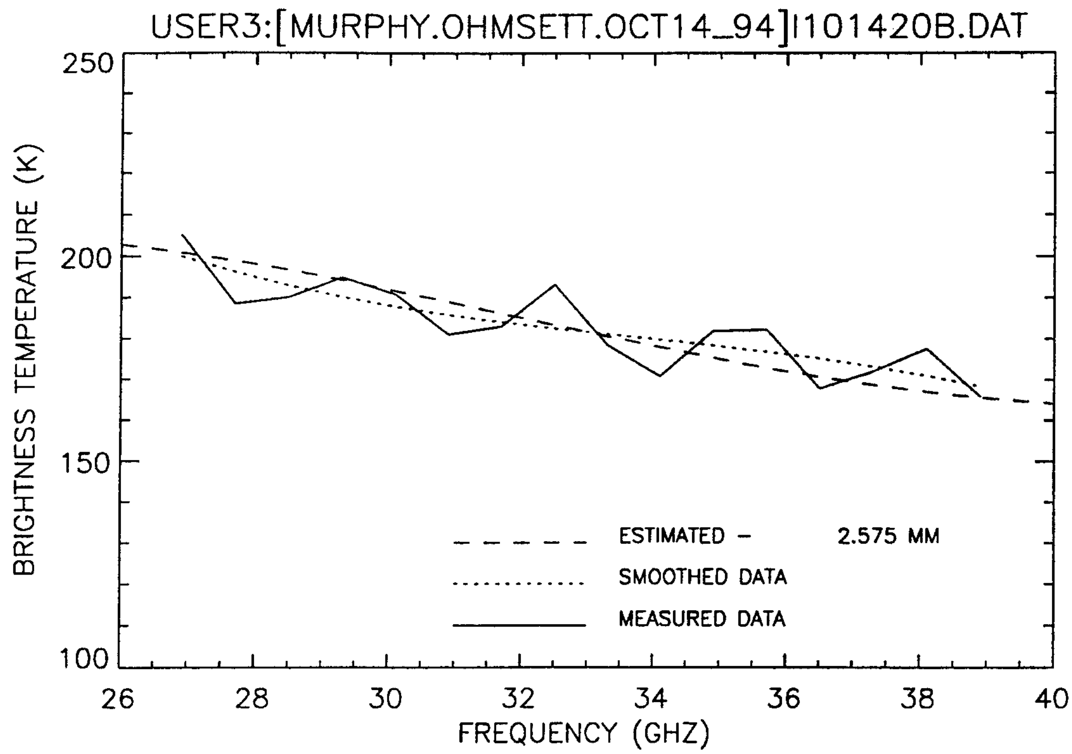

Figure D-122 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Chop Condition 1, 14 October 1994, Pass 2

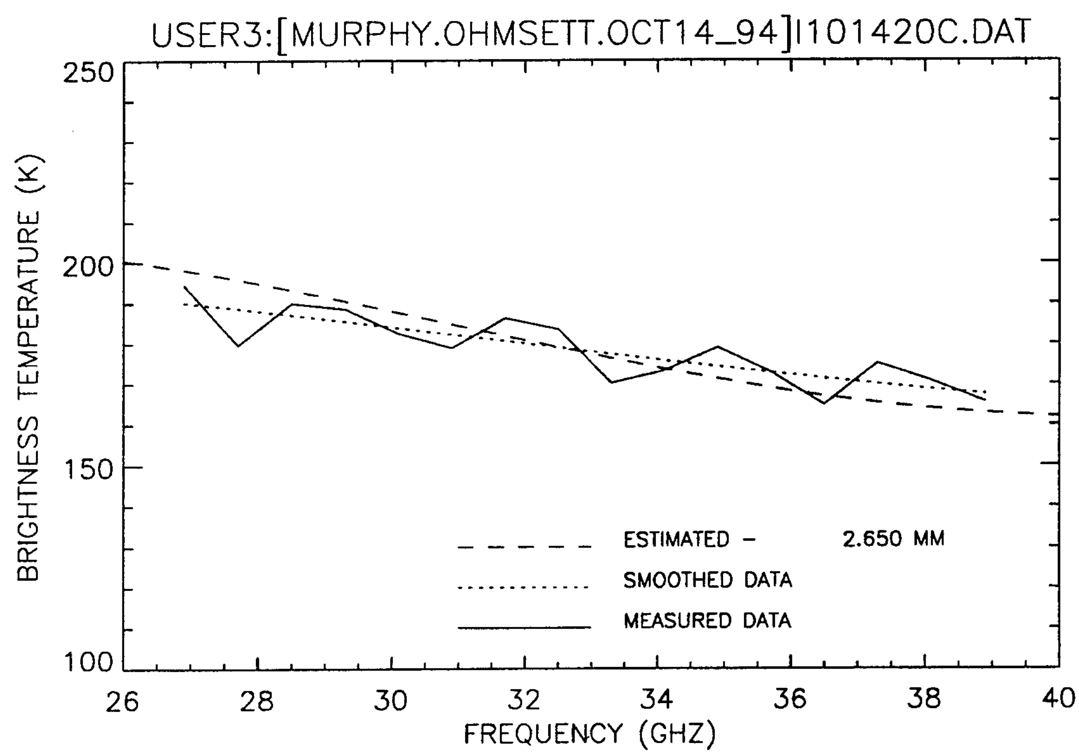

Figure D-123 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Chop Condition 1, 14 October 1994, Pass 3

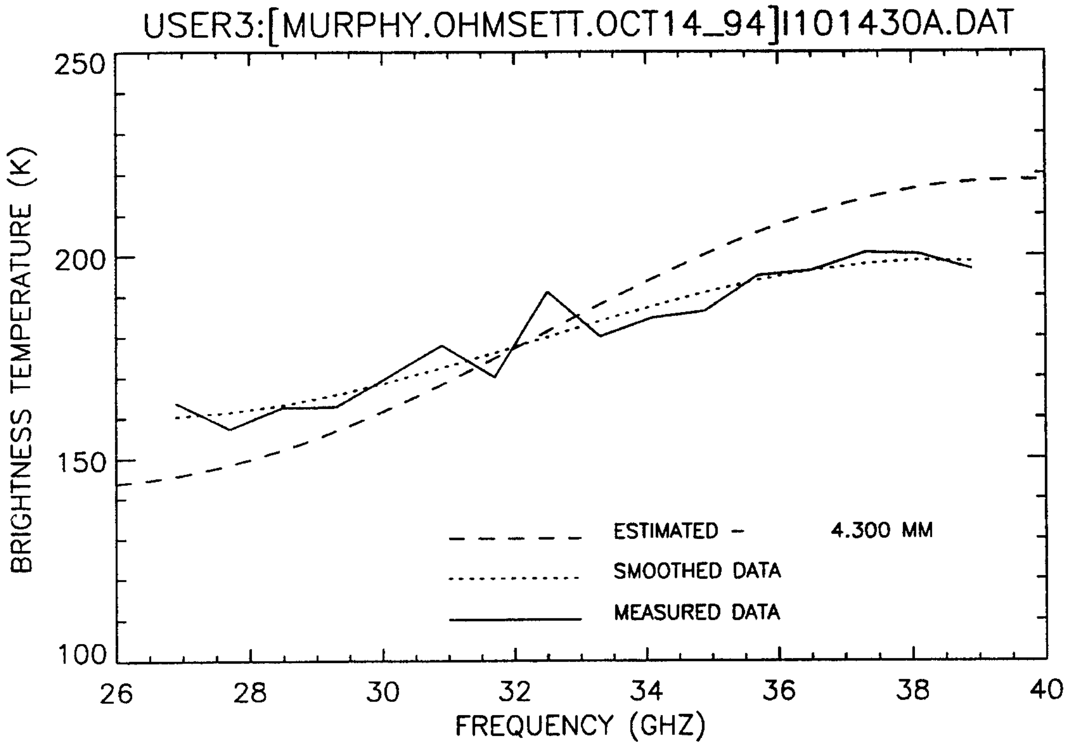

Figure D-124 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Chop Condition 1, 14 October 1994, Pass 1

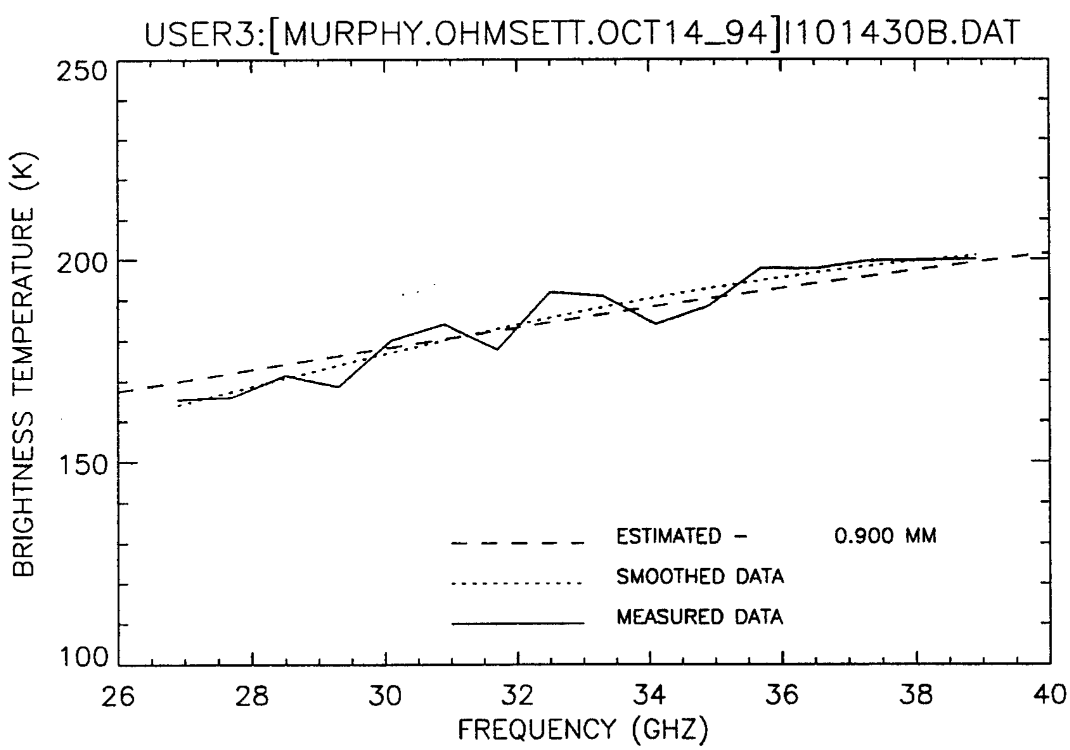

Figure D-125 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Chop Condition 1, 14 October 1994, Pass 2

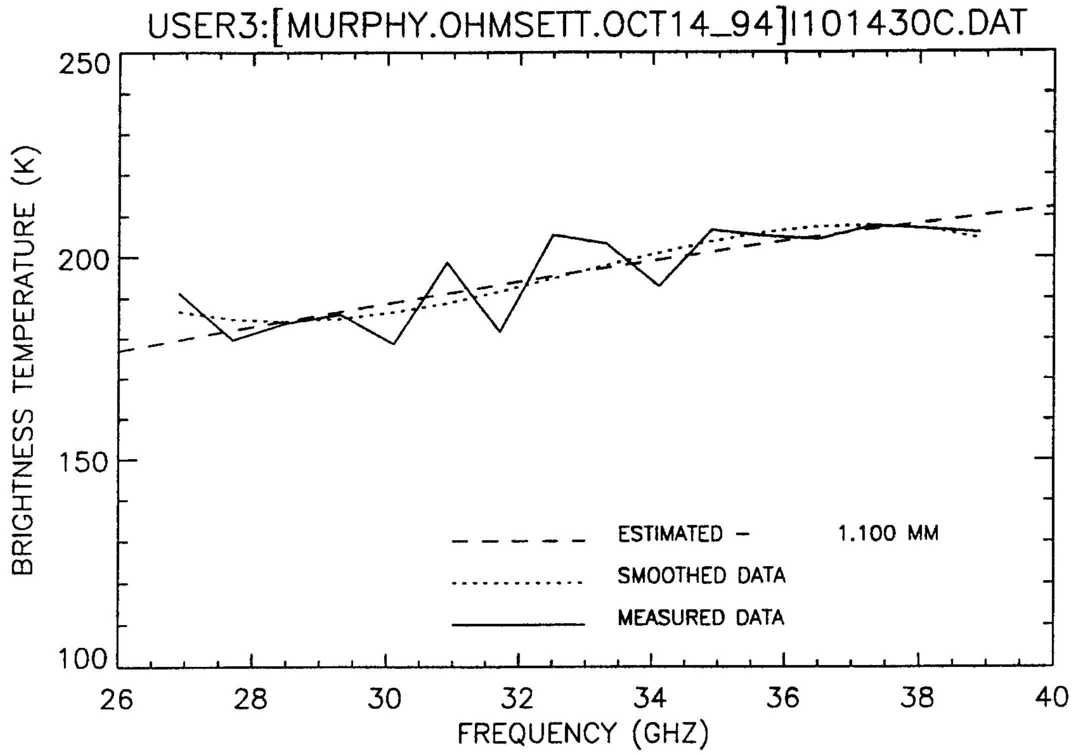

Figure D-126 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Chop Condition 1, 14 October 1994, Pass 3

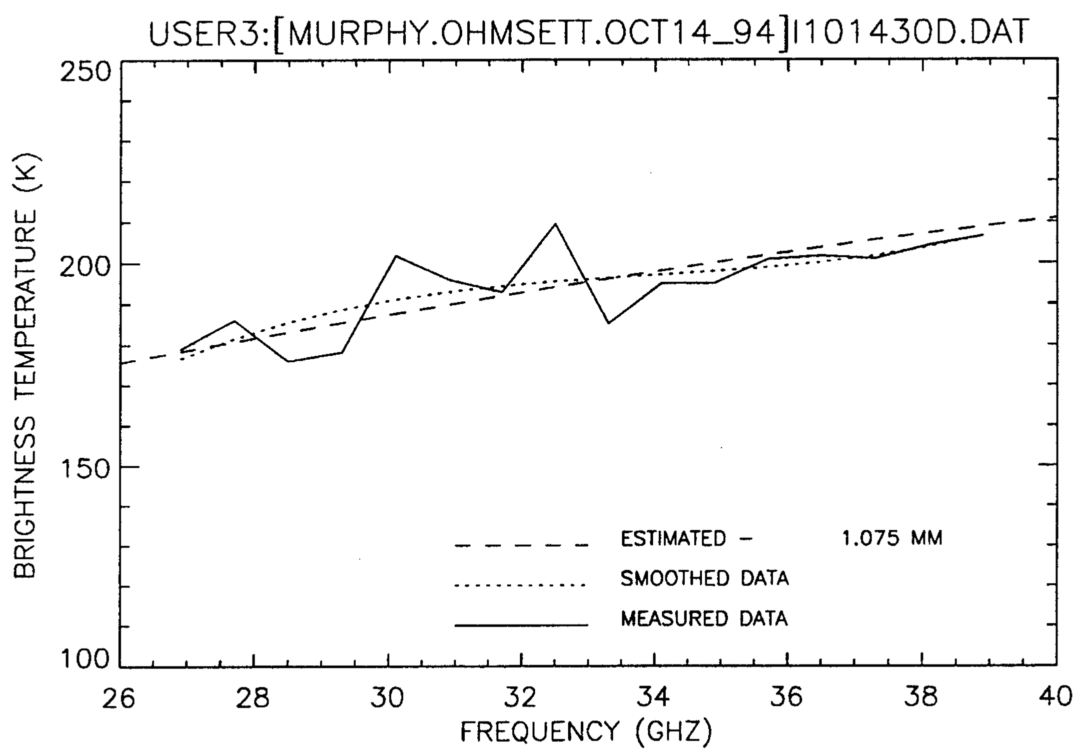

Figure D-127 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Chop Condition 1, 14 October 1994, Pass 4

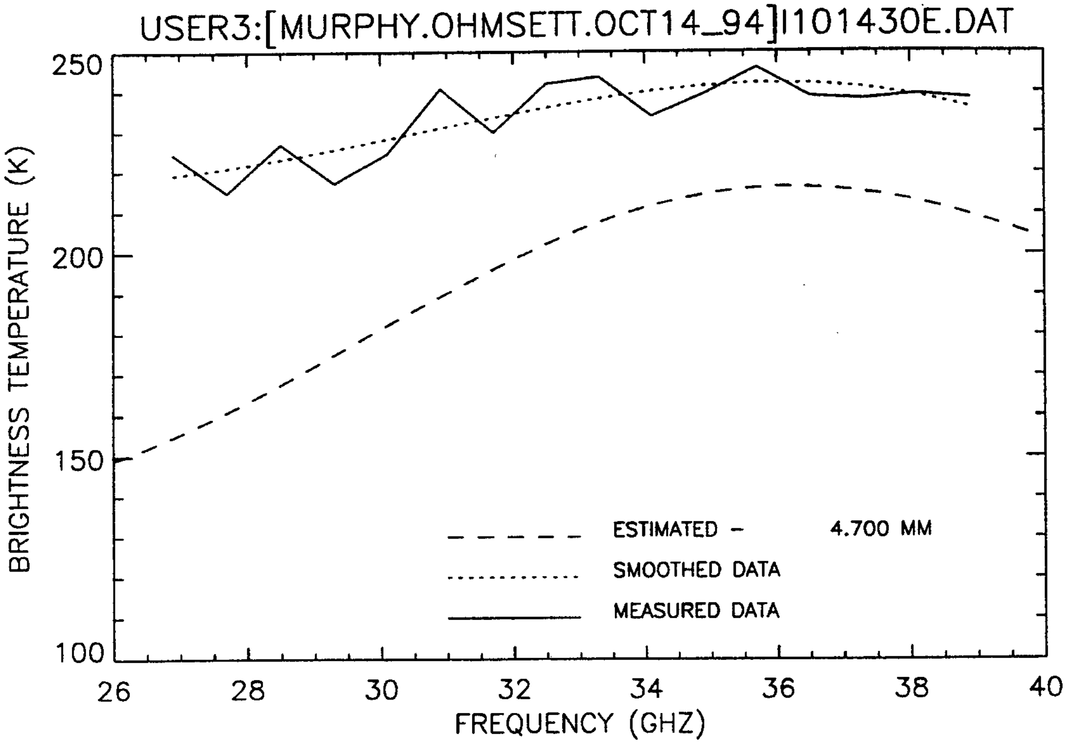

Figure D-128 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Chop Condition 1, 14 October 1994, Pass 5

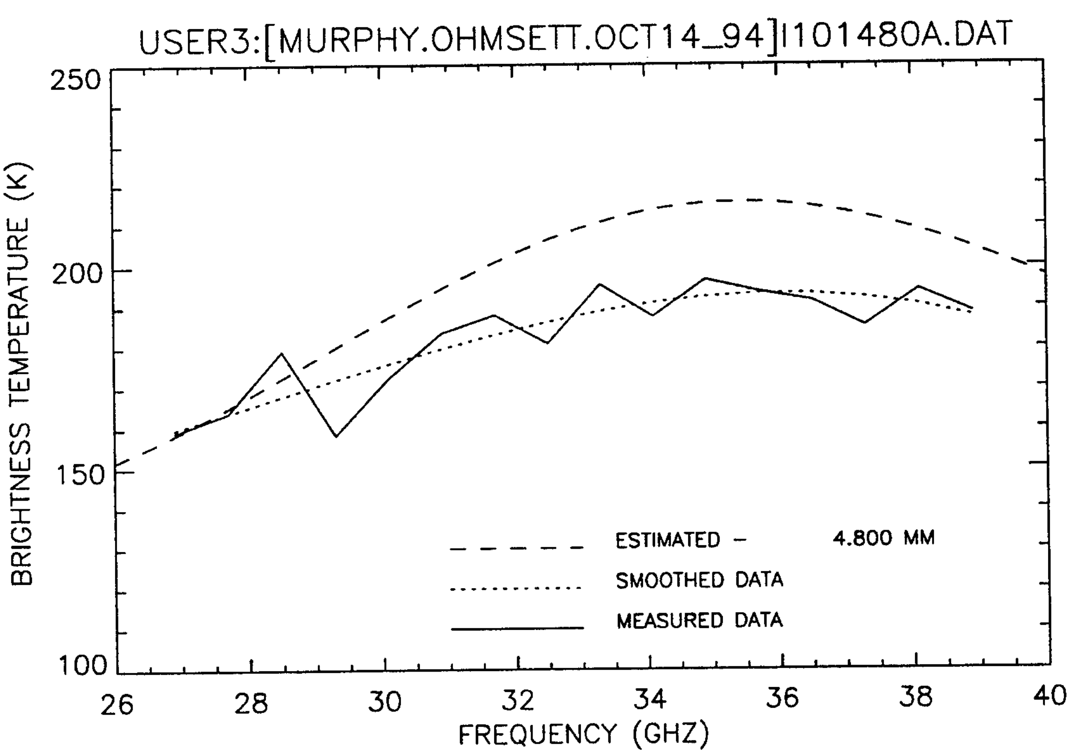

Figure D-129 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Chop Condition 1, 14 October 1994, Pass 1

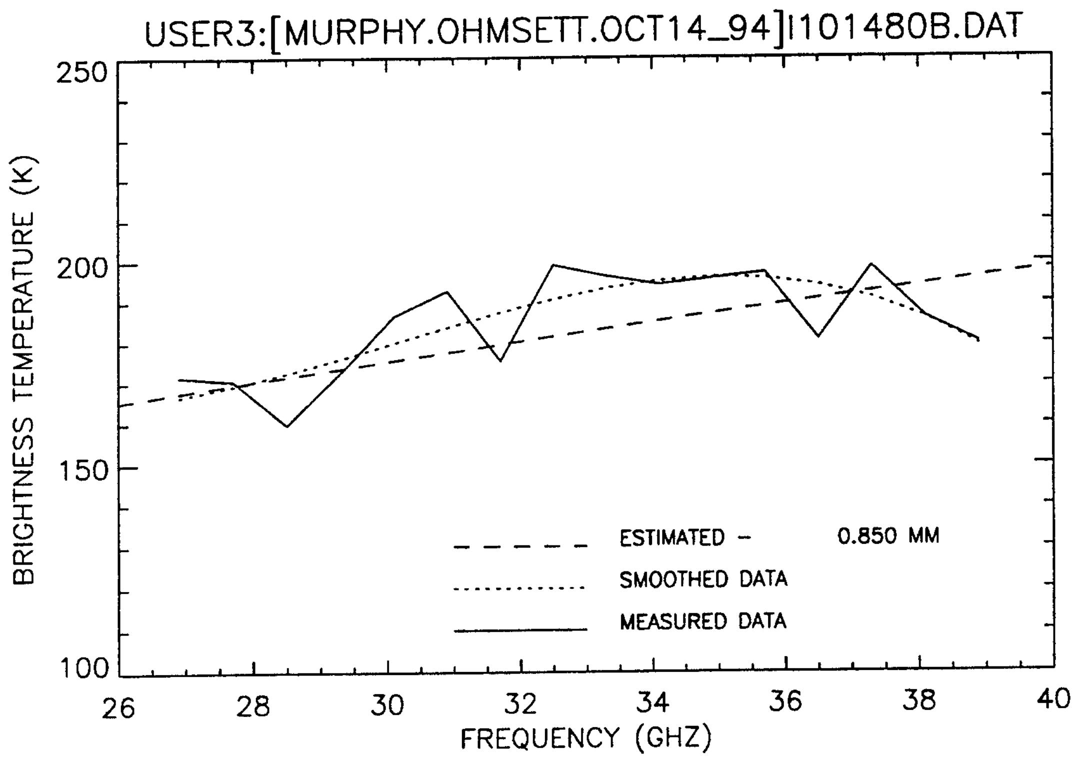

Figure D-130 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Chop Condition 1, 14 October 1994, Pass 2

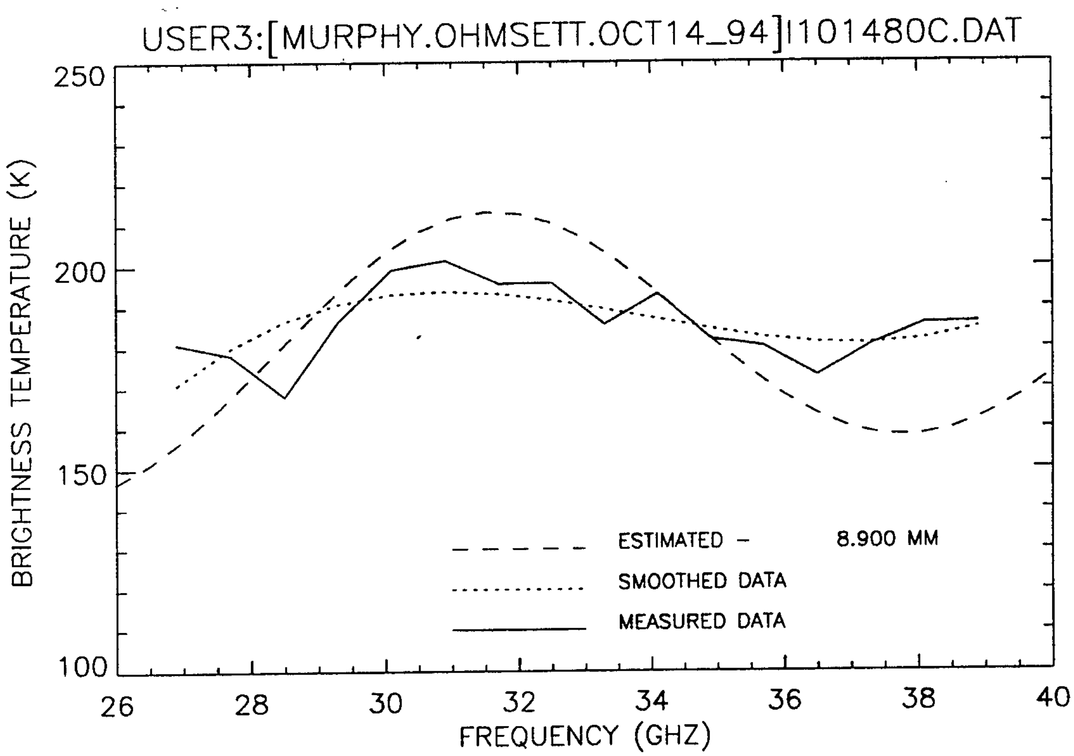

Figure D-131 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Chop Condition 1, 14 October 1994, Pass 3

Following the chop 1 wave condition measurements, the wave generator was reset to provide chop 2 conditions. The waves were allowed to reach a steady-state condition prior to data collection.

J101400A - This is the water reference that was chosen for this set of measurements.

J101400B - This curve is a good match to the algorithm estimate of 0.100 mm.

J101400C - This curve is a good match to the algorithm estimate of 0.275 mm.

J101400D - This curve is a good match to the algorithm estimate of 0.250 mm. These inconsistent background measurements may indicate that the choppy wave conditions introduce significant noise into the T^B measurements.

The main bridge was moved over the center of the 1.0 mm oil target pool. The FSR collected data over an oil target with small areas of foam on the surface.

J101410A - This curve is a poor match to the algorithm estimate of 1.625 mm. The high T^B characteristic indicates that this is an emulsion. The curve has a shape that is vaguely similar to a 4.350 mm estimate (plotted).

J101410B - This curve is a poor match to the algorithm estimate of 1.675 mm, although the shape is similar. The high T^B characteristic indicates that this is an emulsion.

J101410C - This curve is a poor match to the algorithm estimate of 1.700 mm, although the shape is similar. The high T^B characteristic indicates that this is an emulsion.

The main bridge was moved over the center of the 2.0 mm oil target pool. The entire surface of this oil target was foamy.

J101420A - This curve is a poor match to the algorithm estimate of 1.675 mm, although the shape is similar. The high T^B characteristic indicates that this is an emulsion.

J101420B - This curve is a poor match to the algorithm estimate of 1.675 mm, although the shape is similar. The high T^B characteristic indicates that this is an emulsion.

J101420C - This curve is a poor match to the algorithm estimate of 1.675 mm, although the shape is similar. The high T^B characteristic indicates that this is an emulsion.

This measurement was collected over the center of the 3.0 mm oil target. The oil in this target pool had foam on its surface. Four other data sets collected over this pool were inadvertently overwritten.

J101430E - This curve is a poor match to the algorithm estimate of 1.650 mm, although the shape is similar. The high T^B characteristic indicates that this is an emulsion.

The main bridge was positioned over the 8.0 mm oil target pool. The following two measurements are from the center of the pool, with foam covering the entire surface of the oil in the antenna footprint.

J101480A - This curve is a poor match to the algorithm estimate of 1.750 mm, although the shape is similar. The high T^B characteristic indicates that this is an emulsion.

J101480B - This curve is a poor match to the algorithm estimate of 1.675 mm, although the shape is similar. The high T^B characteristic indicates that this is an emulsion.

The main bridge was moved north. The FSR measured a patchy oil target that contained foam on its surface.

J101480C - This curve is a poor match to the algorithm estimate of 1.675 mm, although the shape is similar. The high T^B characteristic indicates that this is an emulsion.

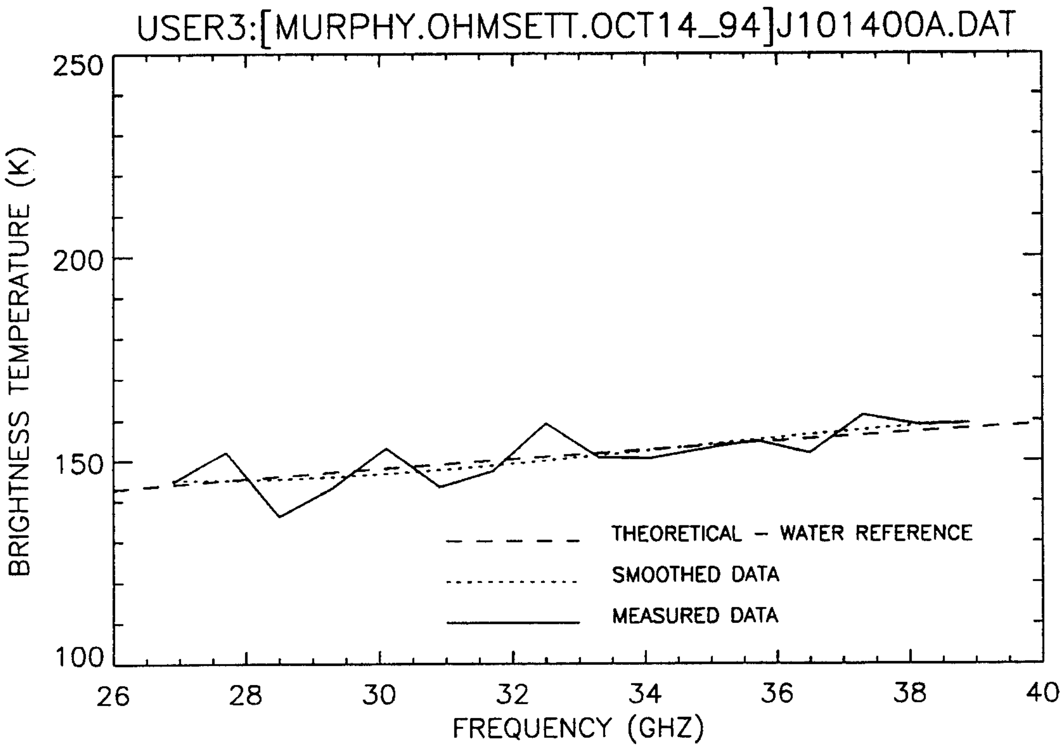

Figure D-132 T^B Versus Frequency Plot for Background Water, Chop Condition 2, 14 October 1994, Pass 1

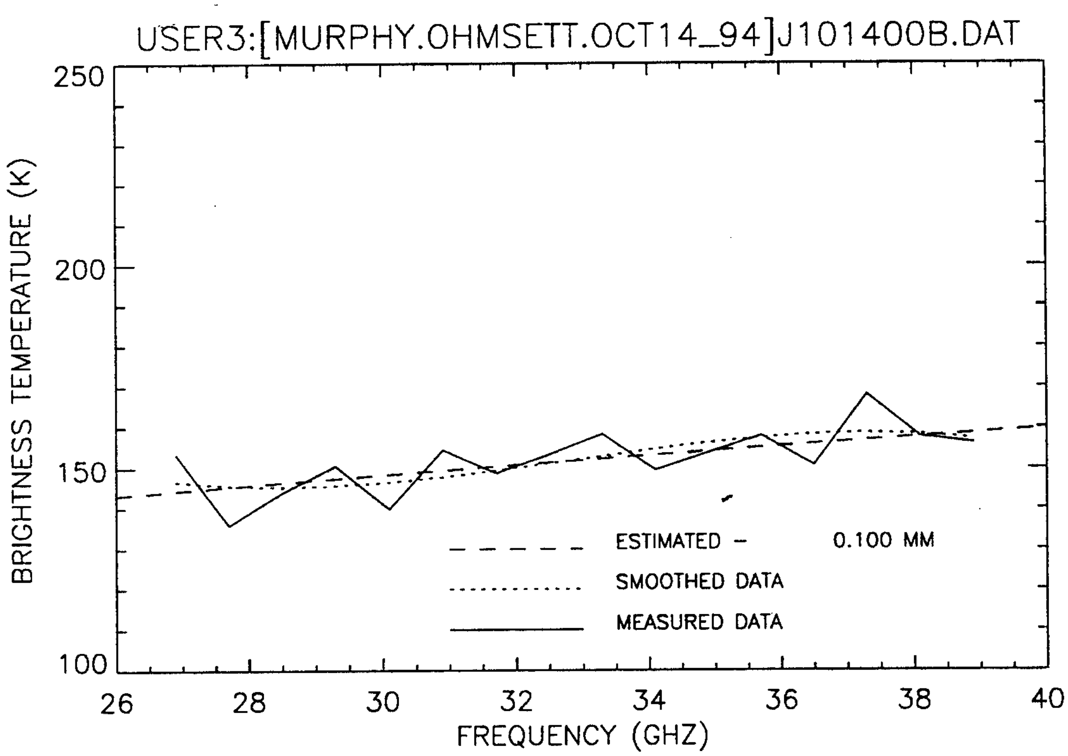

Figure D-133 T^B Versus Frequency Plot for Background Water, Chop Condition 2, 14 October 1994, Pass 2

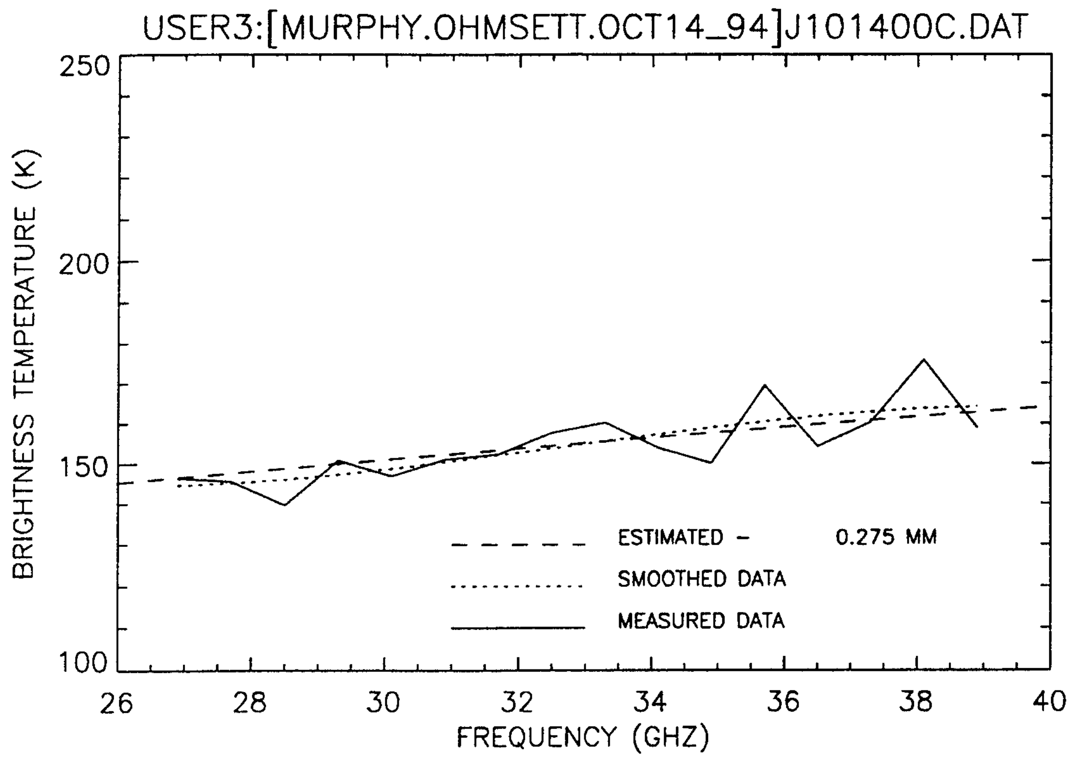

Figure D-134 T^B Versus Frequency Plot for Background Water, Chop Condition 2, 14 October 1994, Pass 3

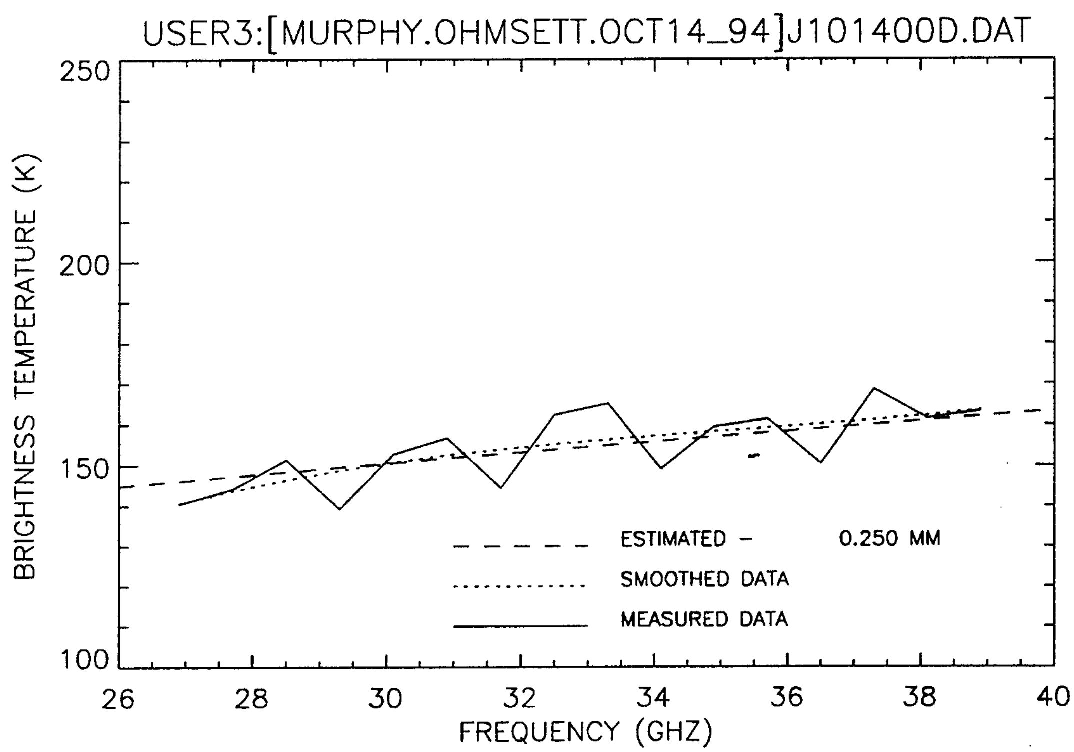

Figure D-135 T^B Versus Frequency Plot for Background Water, Chop Condition 2, 14 October 1994, Pass 4

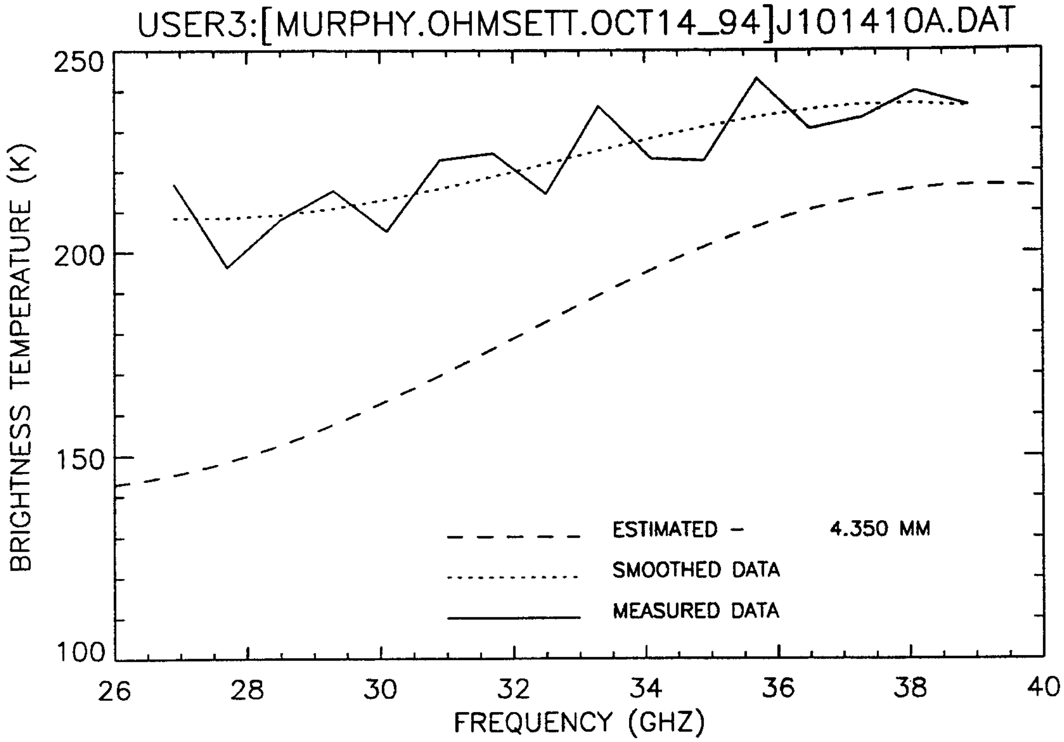

Figure D-136 T^B Versus Frequency Plot for 1.0 mm Oil Thickness, Dyed Diesel, Chop Condition 2, 14 October 1994, Pass 1

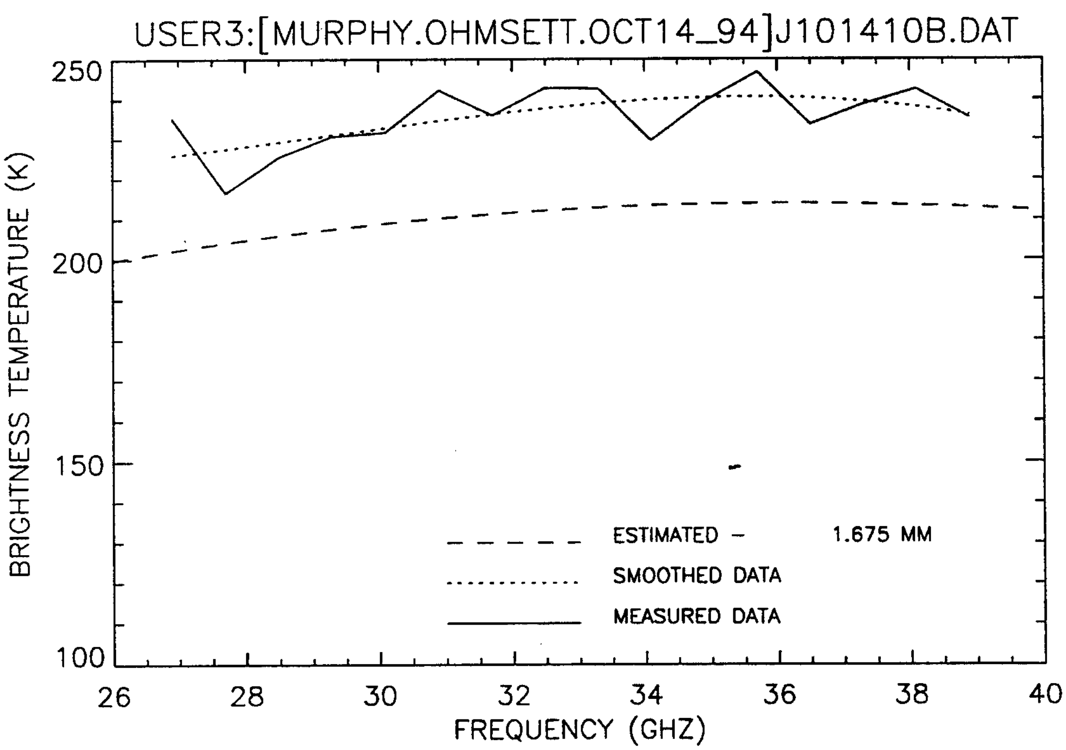

Figure D-137 T^B Versus Frequency Plot for 1.0 mm Oil Thickness, Dyed Diesel, Chop Condition 2, 14 October 1994, Pass 2

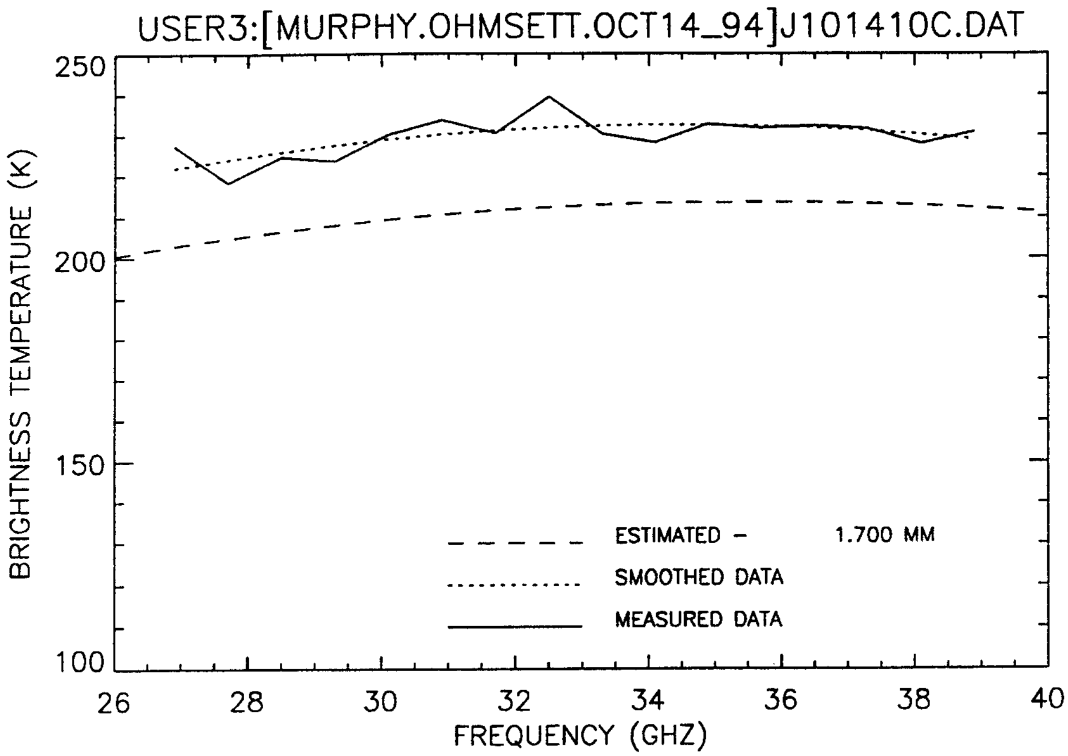

Figure D-138 T^B Versus Frequency Plot for 1.0 mm Oil Thickness, Dyed Diesel, Chop Condition 2, 14 October 1994, Pass 3

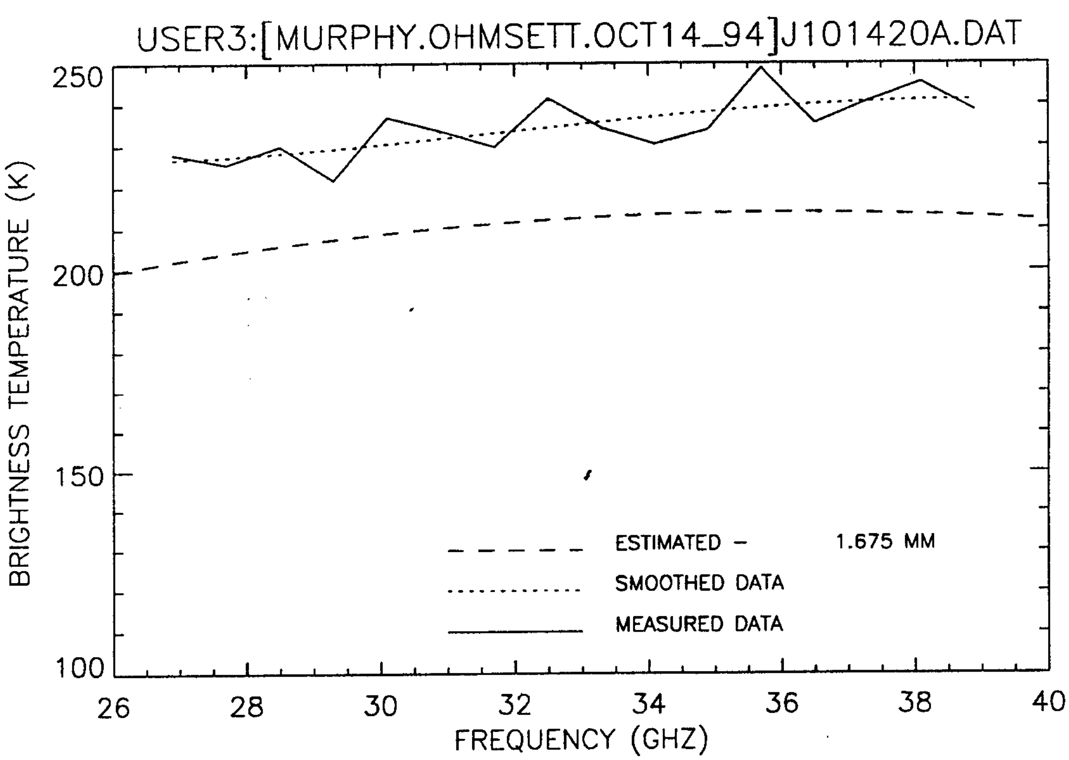

Figure D-139 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Chop Condition 2, 14 October 1994, Pass 1

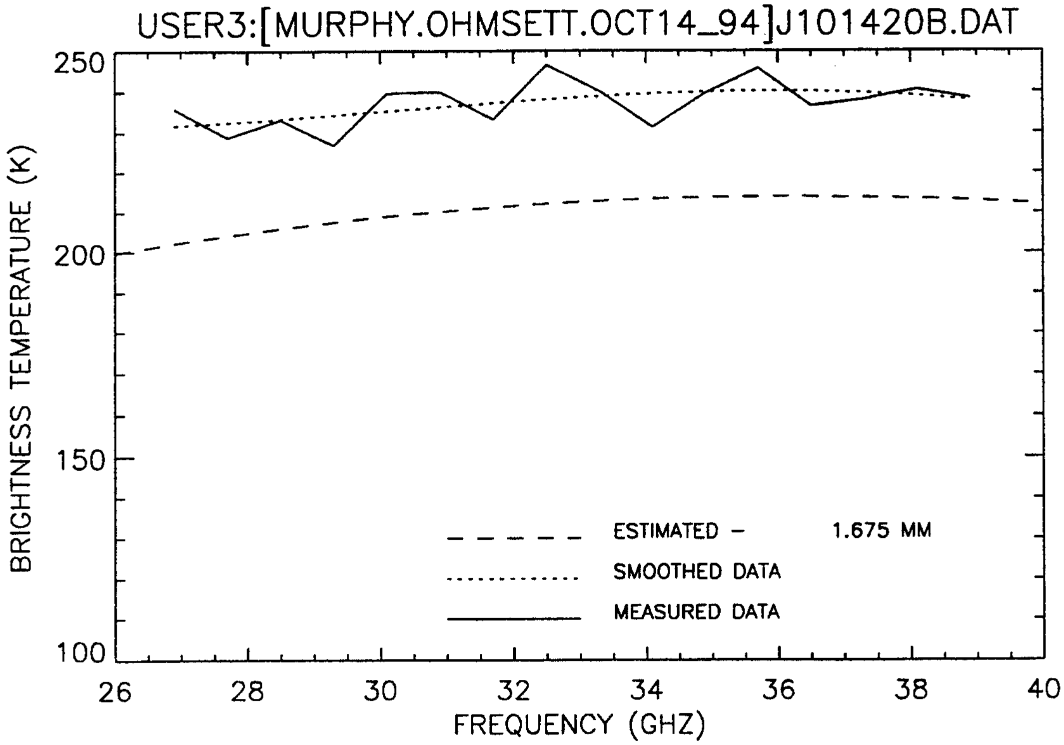

Figure D-140 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Chop Condition 2, 14 October 1994, Pass 2

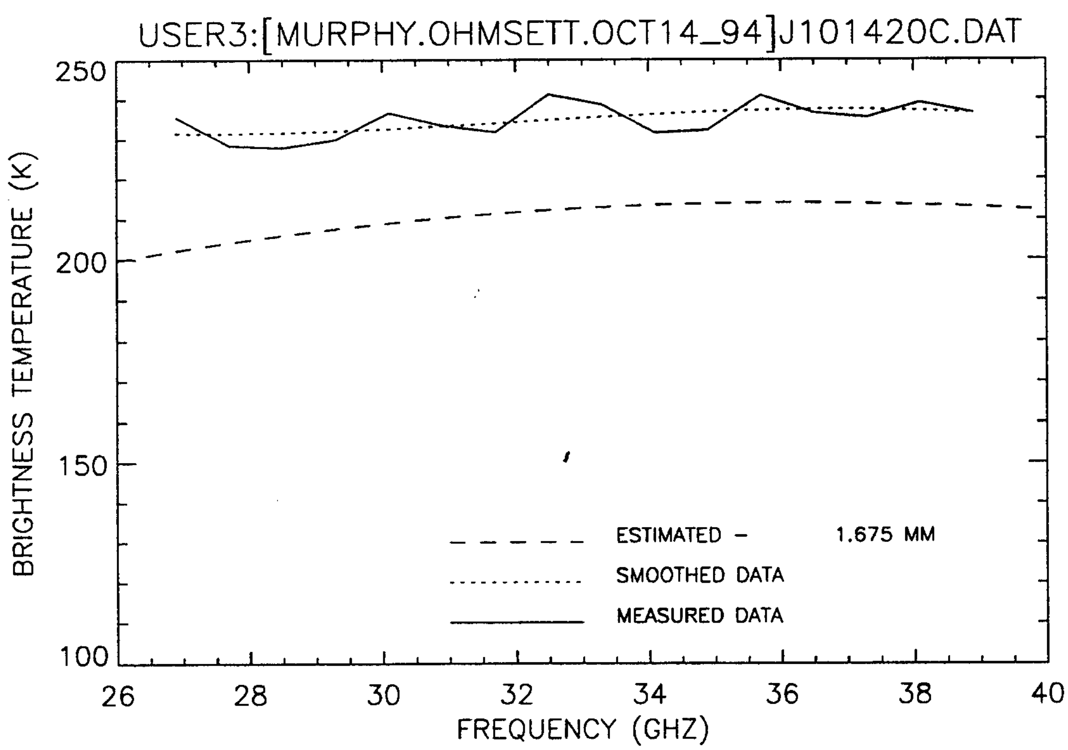

Figure D-141 T^B Versus Frequency Plot for 2.0 mm Oil Thickness, Dyed Diesel, Chop Condition 2, 14 October 1994, Pass 3

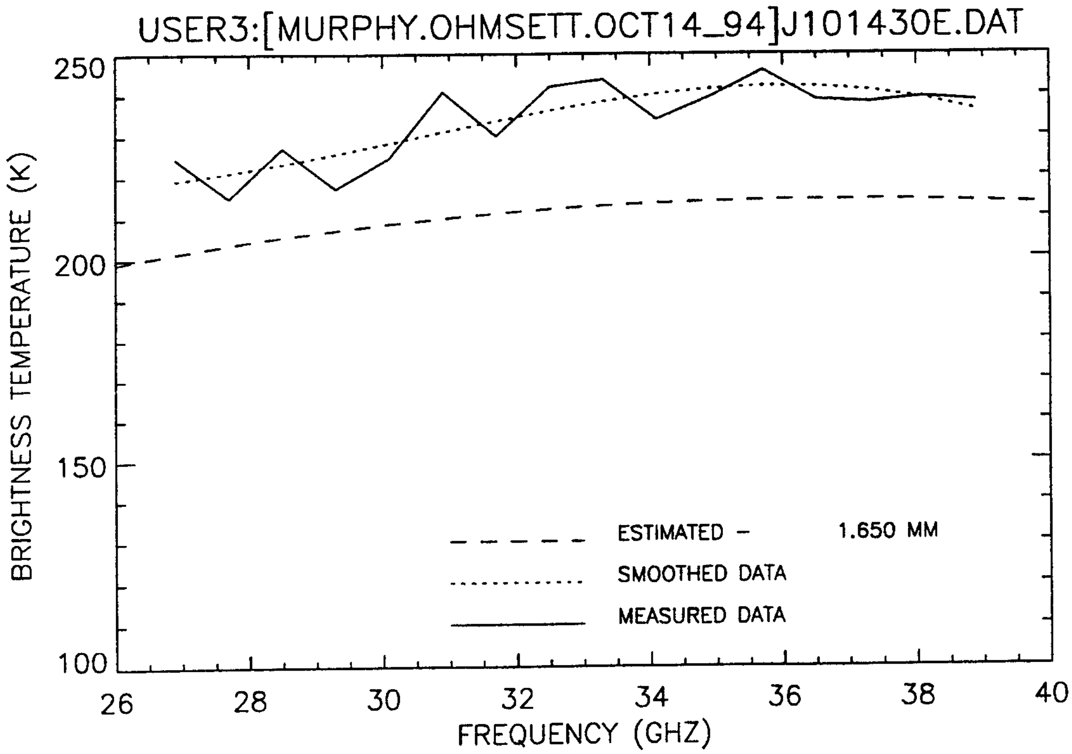

Figure D-142 T^B Versus Frequency Plot for 3.0 mm Oil Thickness, Dyed Diesel, Chop Condition 2, 14 October 1994, Pass 5

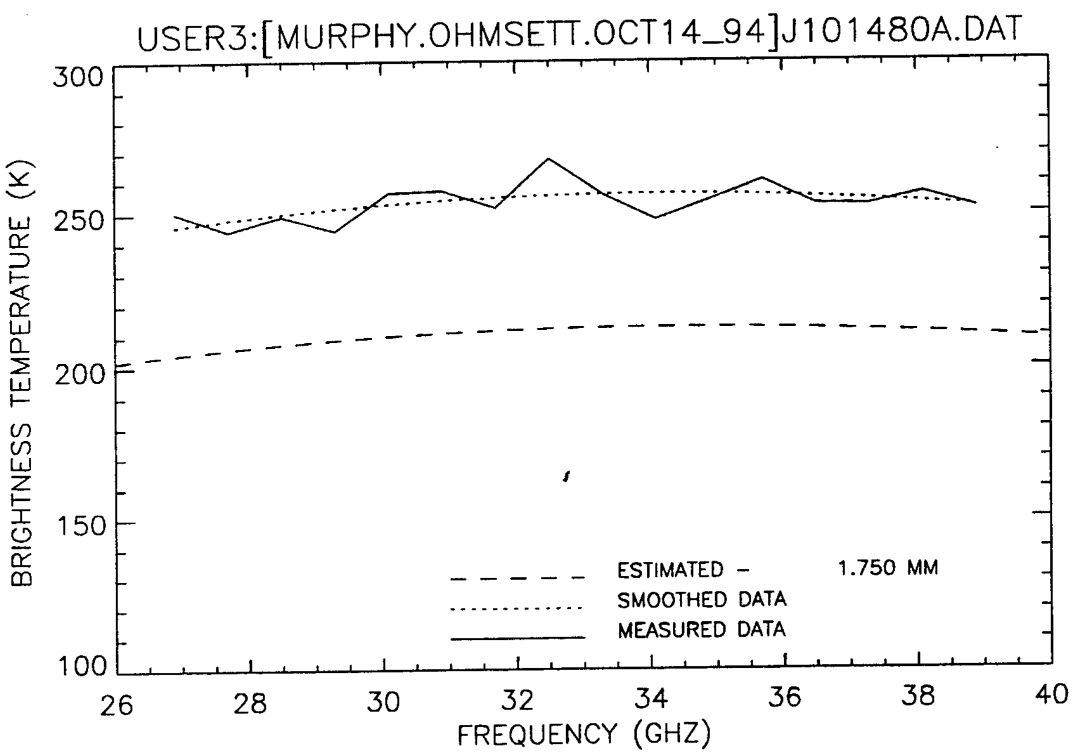

Figure D-143 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Chop Condition 2, 14 October 1994, Pass 1

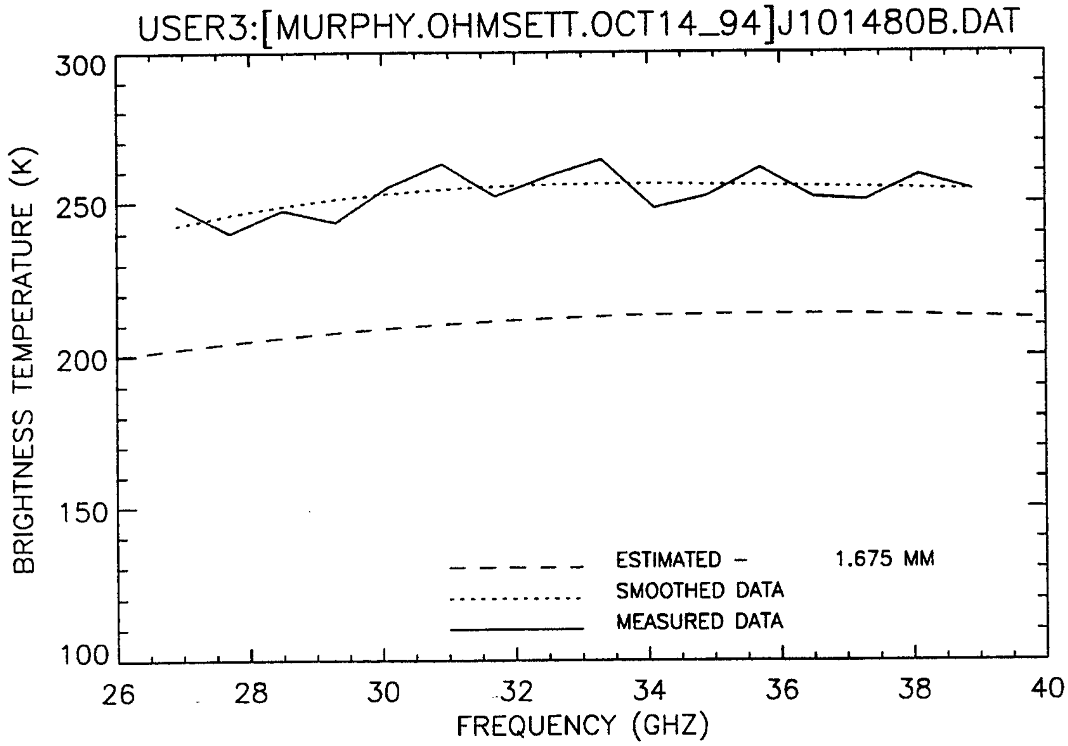

Figure D-144 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Chop Condition 2, 14 October 1994, Pass 2

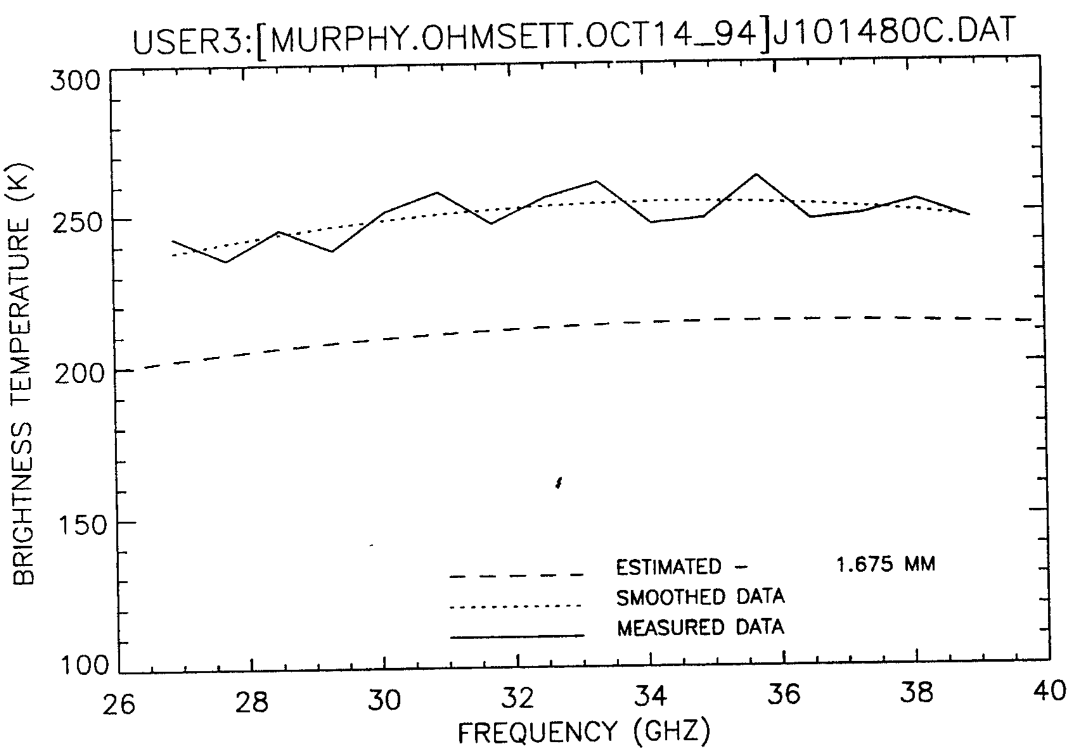

Figure D-145 T^B Versus Frequency Plot for 8.0 mm Oil Thickness, Dyed Diesel, Chop Condition 2, 14 October 1994, Pass 3

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APPENDIX E

BRIGHTNESS TEMPERATURE VERSUS FREQUENCY PLOTS FROM OHMSETT CRUDE OIL TESTS

The frequency scanning radiometer was set up at the OHMSETT facility on the main equipment bridge with the oil pools in the radiometer antenna field of view. Tests were conducted on 17 and 18 October 1994. Measurements were conducted using the Type 2 oil (Alberta Sweet Mix Blend, also referred to as Federated Crude Oil). Measurements under calm conditions were obtained on 17 October 1994. Measurements under calm conditions, two sets of wave conditions and one set of chop conditions were obtained on 18 October 1994.

The file naming convention used for naming most of the data files during this collection was cmmttppx.DAT, where c is a letter identifier for the test session (L = 17 Oct. 94, M, N, P, Q = 18 Oct. 94), mm is the month (10 = October), tt is the intended thickness in tenths of a millimeter, and pp is the intended percentage coverage at that thickness, and x is the pass identifier. Thus, L102510I refers to the ninth (letter "I") measurement taken on 17 October over an oil target pool with a volume of oil that would cover 10% of the target pool surface area with 2.5 mm of oil.

The plots shown in this appendix, figures E-1 through E-139, are radiometric brightness temperature (T^B), expressed in Kelvin (K), as measured by the FSR, versus the measurement frequency, in GHz. Under the current FSR software configuration, sixteen equally spaced points between 26.5 GHz and 40.0 GHz are sampled, with each sample period somewhat less than one second. These sixteen points are plotted as 'measured' points. For each data set, the oil thickness estimation algorithm, described in Chapter 4, is used to estimate an oil film thickness. This algorithm-derived estimate is displayed with the smoothed curve and the declared result plotted over the actual measured points. The data analyst can then either choose to accept the algorithm estimate, or manually select a curve that may be a better fit to the measured data.

The plots in this appendix are arranged by test session. At the beginning of each test session data set, comments are provided for each measurement concerning the fit of the algorithm estimate and the analyst's choice for each curve's best fit.

When viewing the plots, it is important to understand that the figure titles cite only the target oil thickness value within the test pool being viewed. As described in chapter 3, the actual thickness of oil being viewed by the FSR at any given moment could vary substantially from this target value.

The oil targets for the 17 October measurements consisted of the Type 2 oil, with the volume overfilled by 25% to allow evaporation of lighter volatile hydrocarbon products. The oil targets that contained less than 80% anticipated coverage created oil targets that remained close to the oil containment booms.

L101700A - This curve was chosen as reference water temperature for this data set.

L101700B - The second background measurement is noticeably lower than the selected water background measurement. It is believed that the FSR electronics were still warming up and had not yet reached thermal stability.

L101700C - This background measurement is still lower than the selected water background curve. It is believed that the FSR electronics were still warming up and had not yet reached thermal stability. The measured and actual curves do have a good match in slope.

The OHMSETT main bridge was moved for the FSR to collect data from the center of the 2.5 mm, 100% coverage oil target pool. The file names for this set of measurements are slightly different from the naming convention described earlier; the file names here include the date (1017 = Oct. 17) and thickness in tenths of a millimeter (25) instead of the convention using thickness and percent coverage.

L101725A - This curve is a fair match to the algorithm estimate of 4.600 mm. An estimate of 4.375 matches the slope through 35 GHz well but the measured curve does not show as much roll-off near 38 GHz. Overall, the curve has higher T^B than expected for an oil thickness in the 4.3 - 4.6 mm range.

L101725B - This curve is a fair-to-poor match to the algorithm estimate of 4.600 mm. The slope through 35 GHz matches well but the measured curve does not show as much roll-off near 38 GHz. Based on this curve shape, a 4.3 mm estimate given by the correlation result might be a better match. Overall, the curve has higher T^B than expected for an estimate in the 4.3 - 4.6 mm range.

L101725C - This curve is a good match to the algorithm estimate of 4.45 mm. The overall curve shape seems to match the measured data set.

The OHMSETT main bridge was moved for the FSR to collect data from the center of the next oil target pool. The volume of oil in this pool would create a 2.5 mm thickness at 10% coverage. The crude oil appeared to be separating out into two distinct types, (1) the remaining dark areas of dark black crude oil, and (2) thin "scummy" looking areas, a definite layer of a somewhat clear but amber-tinted liquid. The following measurements were from the "scummy" area in the center of the oil target.

L102510A - This curve is a poor match to the algorithm estimate of 0.0 mm. The curve shape is not recognizable as any of the T^B family curves. If the measurement didn't have such a low response between 36 - 39 GHz it would seem to match the 0.0 mm estimate. The results are inconclusive.

L102510B - This curve is a poor match to the algorithm estimate of 0.0 mm. The curve shape is not recognizable as any of the T^B family curves. If the measurement didn't have such a low response between 36 - 39 GHz it would seem to match the 0.0 mm estimate. The result is inconclusive.

Although the on-site notes did not record internal hot load calibrations, it is possible that an internal calibration was performed between the L102510B and L102510C measurement. Comparing the L102510A - B curves with the L102510C - E, the most noticeable difference is the measured response at 37 GHz and 38 GHz. Since the instrument is measuring the same spot on the oil target, the low data samples at the 37 and 38 GHz frequencies for L102510A - B may be due to instrument drift.

L102510C - This curve is a good-to-excellent match to the algorithm estimate of 0.150 mm.

L102510D - This curve is good-to-excellent match to the algorithm estimate of 0.0 mm.

L102510E - This curve is a good match to the algorithm estimate of 0.0 mm.

The OHMSETT main bridge was moved 2 - 3 feet north, to measure a different part of the oil target. In this case the FSR beam fill was 60% "scummy" oil, 40% crude oil.

L102510F - This curve is a poor match to the algorithm estimate of 0.675 mm. The curve seems flat with no positive slope. If a partial beam fill of 40% is used to generate the theoretical prediction curve, (the 40% fill matches the on-site estimate of crude oil in the antenna beam) a 1.9 mm estimate (plotted) is an excellent match.

L102510G - This curve is a poor match to the algorithm estimate of 0.625 mm. The curve seems flat with no positive slope. If a partial beam fill of 35% is used to generate the theoretical prediction curve (the 35% fill is slightly lower than the on-site estimate of crude oil in the antenna beam), a 1.9 mm estimate (plotted) is an excellent match.

L102510H - This curve is a poor match to the algorithm estimate of 0.65 mm. The curve seems flat with no positive slope. A partial beam fill of 35% is used to generate the theoretical prediction curve (the 35% fill is slightly

lower than the on-site estimate of crude oil in the antenna beam), a 1.9 mm estimate (plotted) is an excellent match.

The OHMSETT main bridge was moved north again so the FSR beam fill was 100% crude oil.

L102510I - This curve is a fair match to the algorithm estimate of 1.225 mm. If an 85% beam fill is assumed, a 1.5 mm estimate (plotted) is a much better match.

L102510J - This curve is a fair match to the algorithm estimate 1.175 mm. If an 85% beam fill is assumed, a 1.5 mm estimate (plotted) is a much better match.

L102510K - The curve is a fair match to the algorithm estimate of 1.2 mm. If an 85% beam fill is assumed, a 1.5 mm estimate (plotted) is a much better match.

The OHMSETT bridge was moved to the northern end of pool where there was oil coverage to support a 50 - 60% FSR antenna beam fill.

L102520A - This curve is a poor match to the algorithm estimate of 0.7 mm. The curve seems flat with little positive slope that is usually seen in thin oil measurements. The shape seems consistent with a thicker estimate. If a 1.8 mm thickness estimate with a 40% beam fill is assumed, the resulting plot is an excellent match to the measured data.

L102520B - This curve is a fair match to the algorithm estimate of 0.625 mm; however, the shape seems consistent with a thicker estimate. If a 1.8 mm thickness estimate with a 40% beam fill is assumed, the resulting plot is an excellent match to the measured data.

L102520C - This curve is a fair match to the algorithm estimate of 0.75 mm; however, the shape seems consistent with a thicker estimate. If a 1.8 mm

thickness estimate with a 40% beam fill is assumed, the resulting plot is an excellent match to the measured data.

The OHMSETT main bridge was moved to the next oil target pool. This pool contained a crude oil volume intended to cover 40% of the surface area at a thickness of 2.5 mm. Measurements start at the south end of this oil target pool. The antenna beam fill is estimated to be 90%.

L102540A - This curve is a fair-to-good match to the algorithm estimate of 2.675 mm.

L102540B - This curve is a fair-to-good match to the algorithm estimate of 2.650 mm.

L102540C - This curve is a fair-to-good match to the algorithm estimate of 2.550 mm.

The main bridge was moved 2 - 3 feet north in the same oil target pool to obtain a 80% antenna beam fill. The antenna footprint is centered on a thin "dividing line" of water that separated two crude oil covered areas .

L102540D - This curve is a poor match to the algorithm estimate of 2.4 mm. The curve would be a good shape match to the 1.9 mm correlation result, but overall the T^B is too low. If a 70% beam fill is used to generate the theoretical prediction, then the 2.0 mm estimate (plotted) is an excellent match to the measured data.

L102540E -This curve is a poor match to the algorithm estimate of 2.475 mm. The curve has a good shape match to the 1.9 mm correlation result, but overall the T^B is too low. If a 65% beam fill is used to generate the theoretical prediction, then the 2.0 mm estimate (plotted) is an excellent match to the measured data.

The main bridge was moved north again, close to the northern end of the oil target pool. The oil target had a large "stripe" of water in center (approximately

one foot) compared to the previous measurements. The antenna beam fill is estimated to be 35%.

L102540F - This curve is a poor match to the algorithm estimate of 0.85 mm. The measurement has a somewhat flat response. The measured data set seems to be noisy. The result is inconclusive.

L102540G - This curve is a fair match to the algorithm estimate of 0.725 mm. The measurement has a somewhat flat response. The curve has a good shape match to a 1.8 mm estimate. Using a 40% beam fill at a thickness of 1.8 mm (plotted) produces an excellent match.

L102540H -This curve is a poor match to the algorithm estimate of 0.75 mm. The measured data set seems to be noisy. A 9.5 mm sinusoidal characteristic is noted, as given by the correlation result, although its amplitude modulation is quite low. The result is inconclusive.

L102540I - This curve is a poor match to the algorithm estimate of 0.725 mm. The measured data set seems to be noisy. A 9.7 mm sinusoidal characteristic is noted, as given by the correlation result, although its amplitude modulation is quite low. The result is inconclusive.

The OHMSETT main bridge was moved to the center of a new target pool which contained a crude oil volume intended to cover 80% of the surface area at a 2.5 mm thickness. The antenna beam fill is 100%.

L102580A - This curve is a good match to the algorithm estimate of 1.225 mm.

L102580B - This curve is a good match to the algorithm estimate of 1.300 mm.

L102580C - This curve is a good match to the algorithm estimate of 1.350 mm.

The main bridge was moved to the north end of the pool where there were small gaps in the oil coverage. The estimated antenna beam fill is 95%.

L102580D - This curve is a poor match to the algorithm estimate of 2.175 mm. The curve has a somewhat flat response. The result of using a partial

beam fill of 1.8 mm thickness with 80% beam fill (plotted) is an excellent match.

L102580E - This curve is a poor match to the algorithm estimate of 2.45 mm. The curve has a somewhat flat response. The curve shape is not recognizable as any of the T^B family curves. Partial beam fill methods did not yield better results. The result is inconclusive.

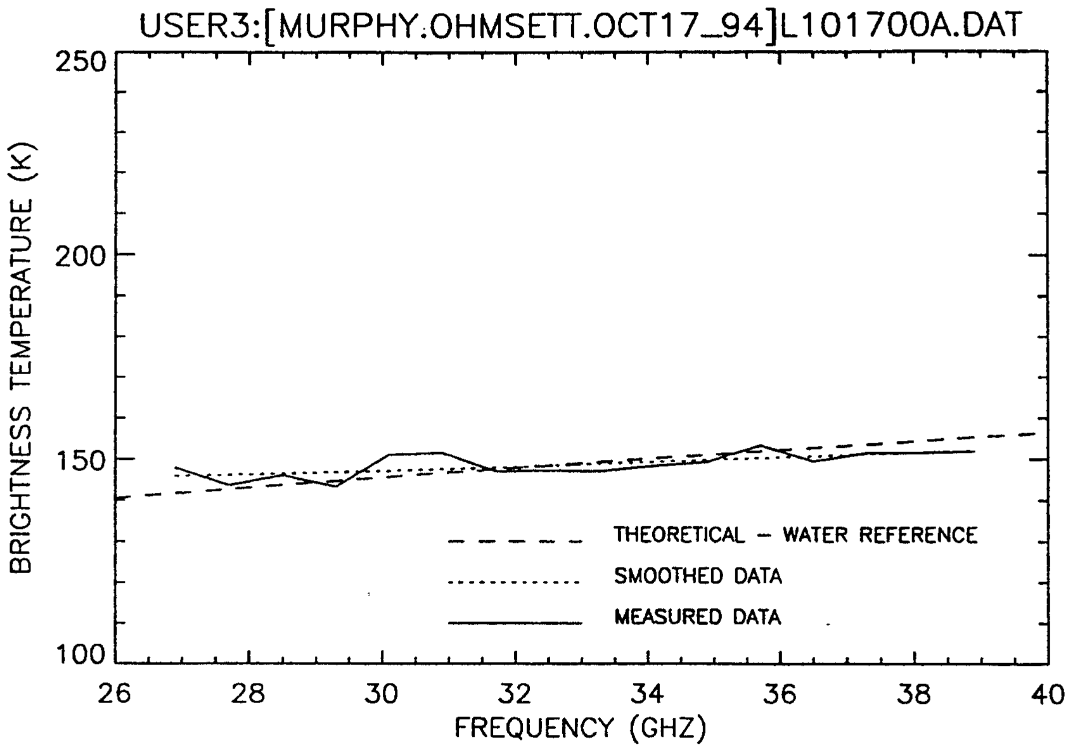

Figure E-1 T^B Versus Frequency Plot for Background Water, 17 October 1994, Pass 1

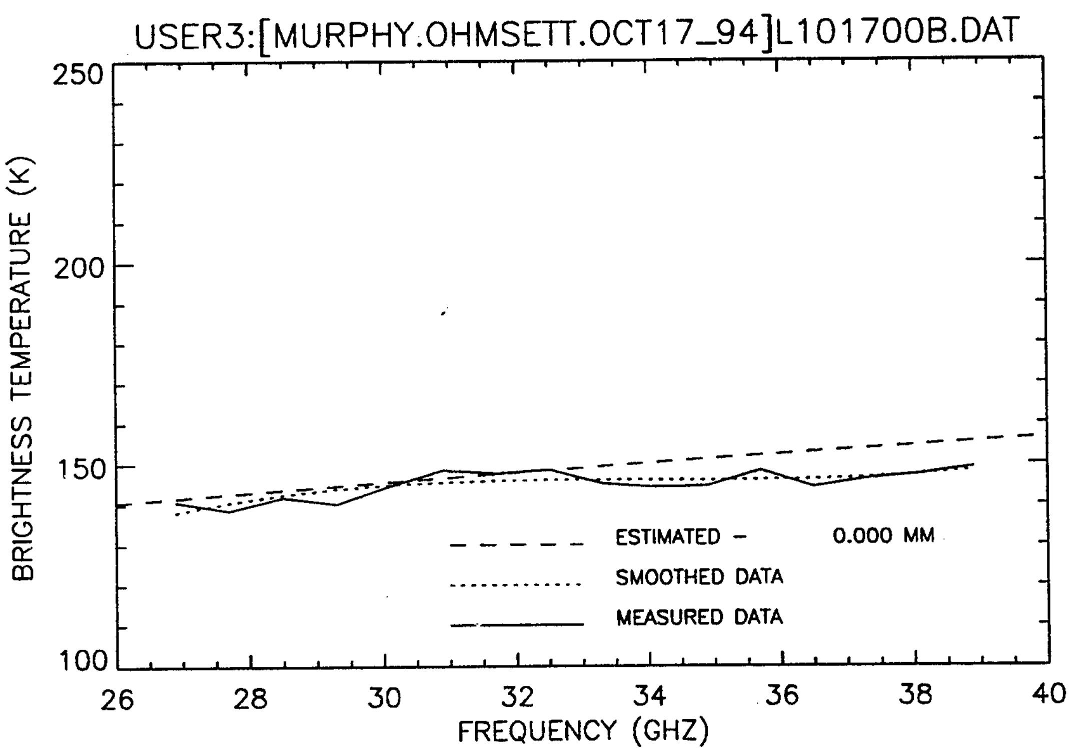

Figure E-2 T^B Versus Frequency Plot for Background Water, 17 October 1994, Pass 2

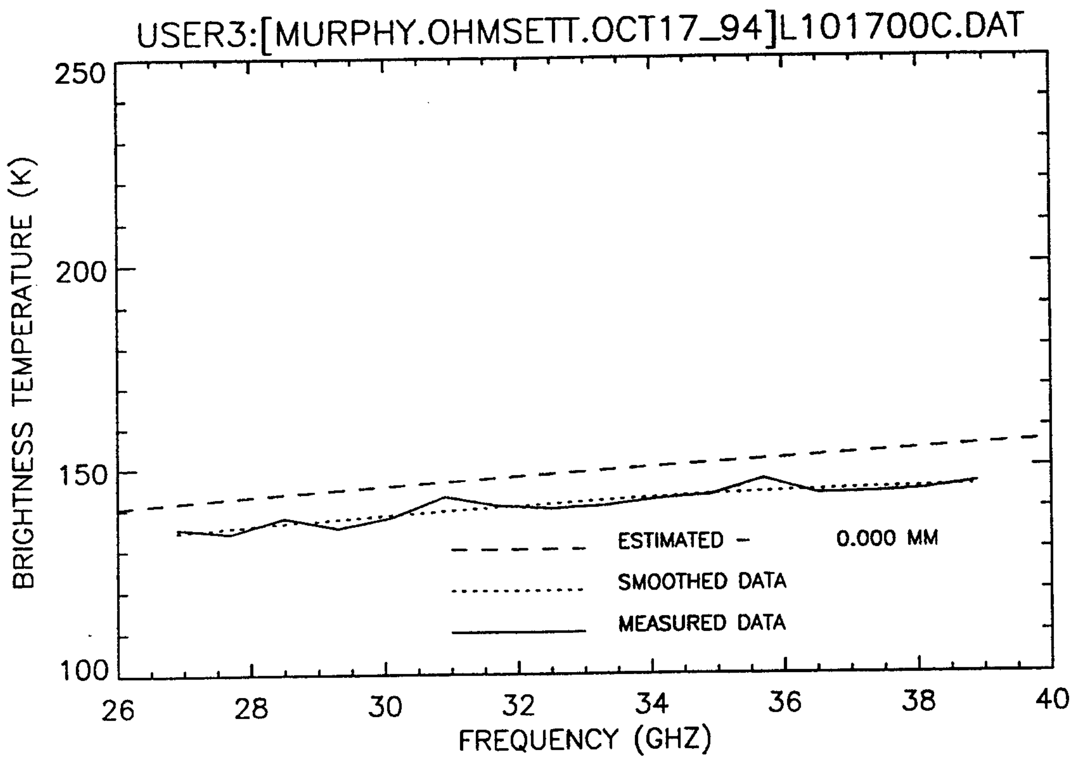

Figure E-3 T^B Versus Frequency Plot for Background Water, 17 October 1994, Pass 3

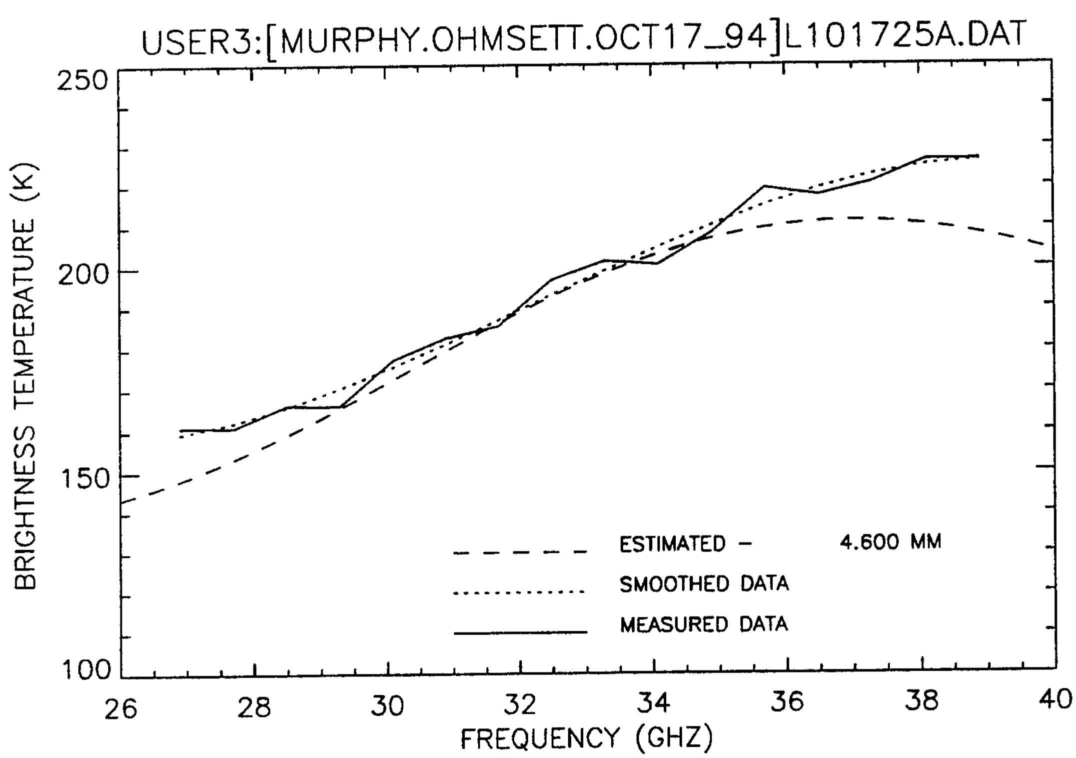

Figure E-4 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, 17 October 1994, Pass 1

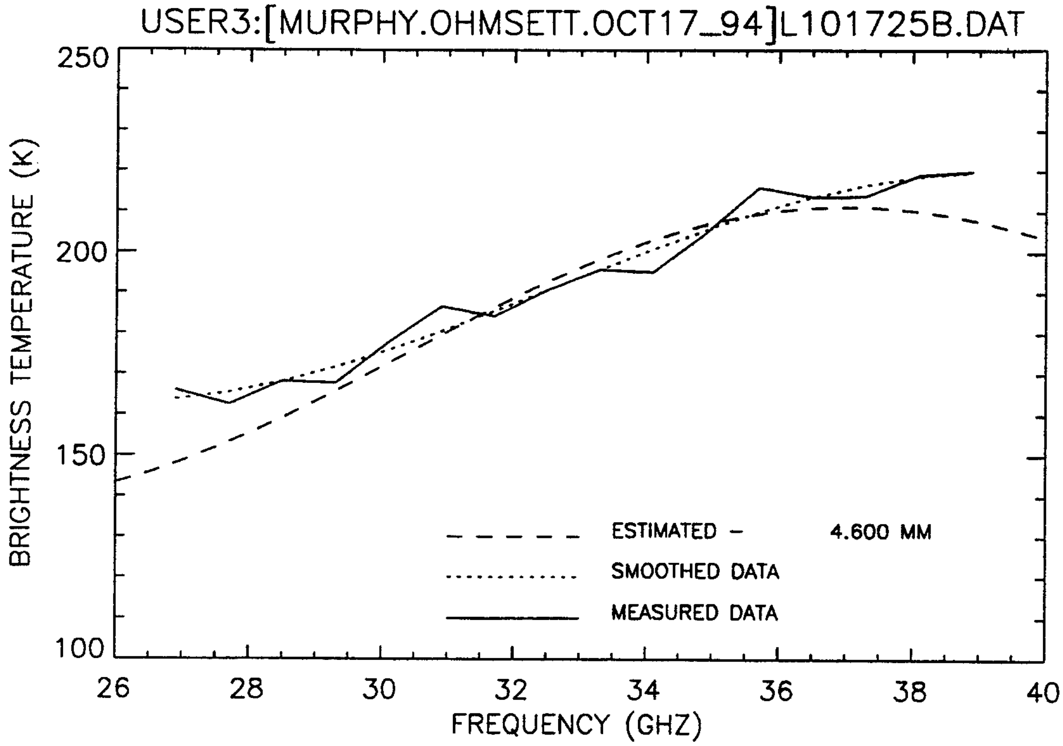

Figure E-5 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, 17 October 1994, Pass 2

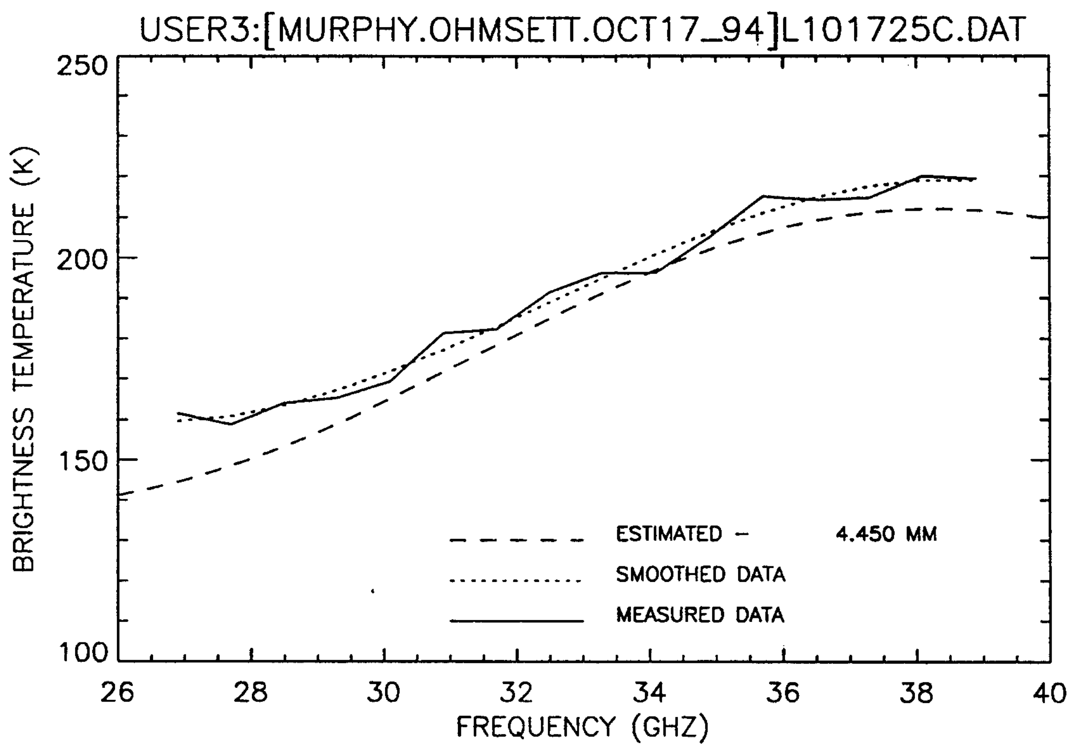

Figure E-6 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, 17 October 1994, Pass 3

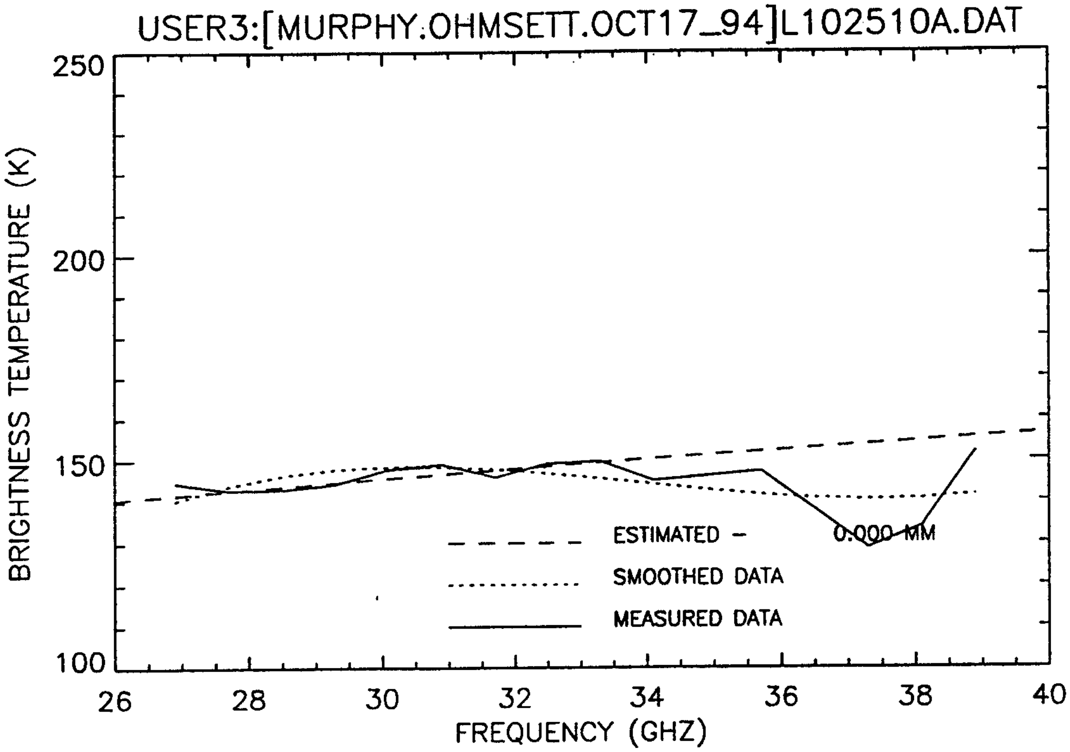

Figure E-7 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, 17 October 1994, Pass 1

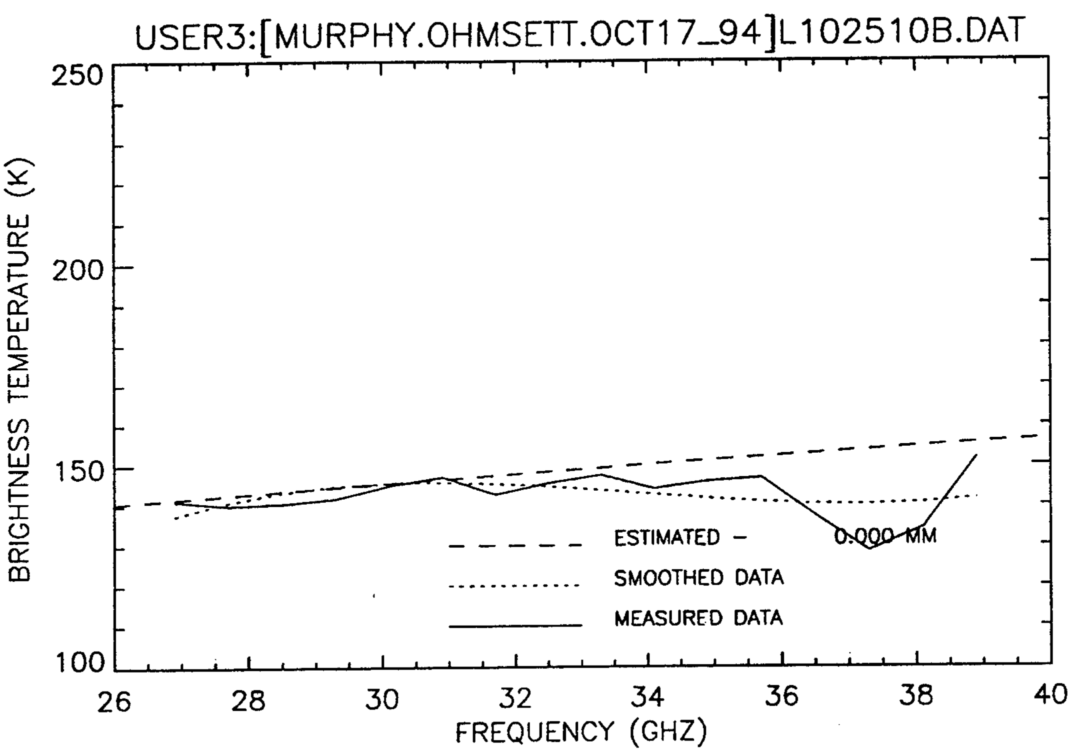

Figure E-8 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, 17 October 1994, Pass 2

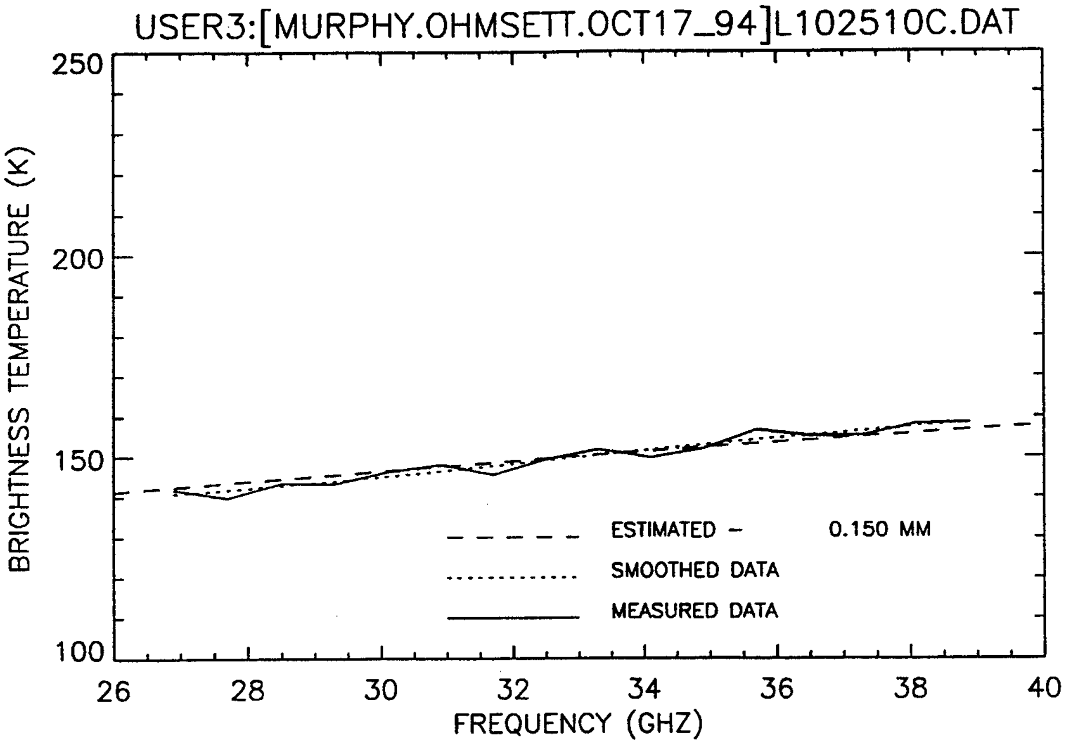

Figure E-9 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, 17 October 1994, Pass 3

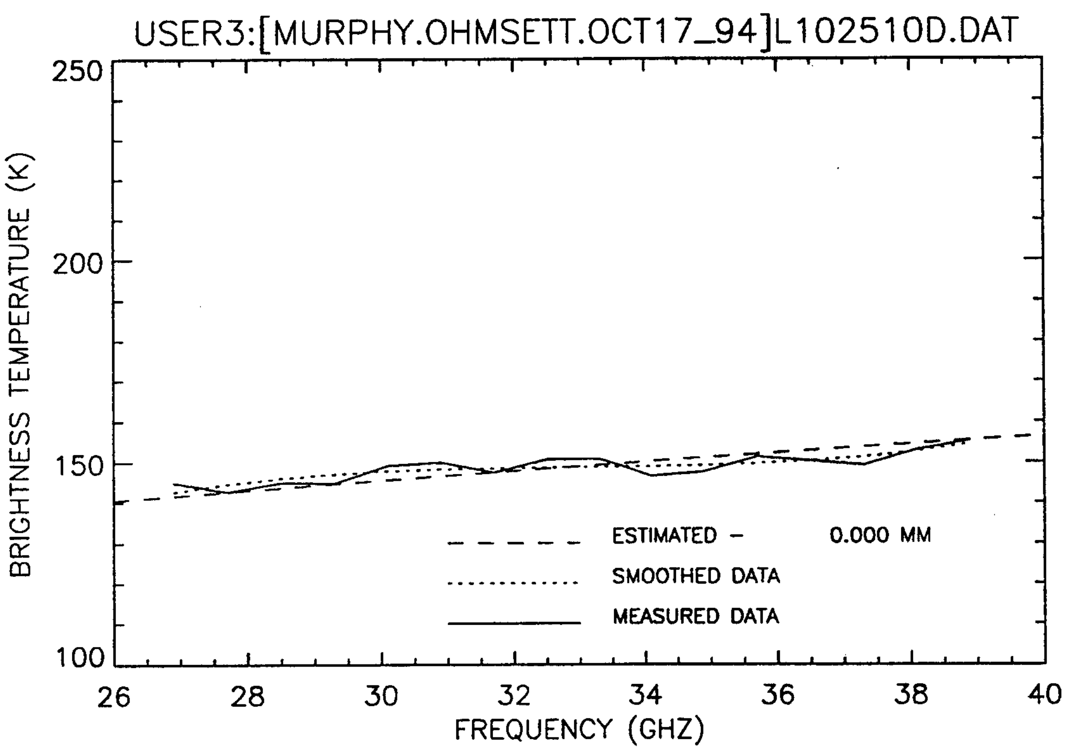

Figure E-10 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, 17 October 1994, Pass 4

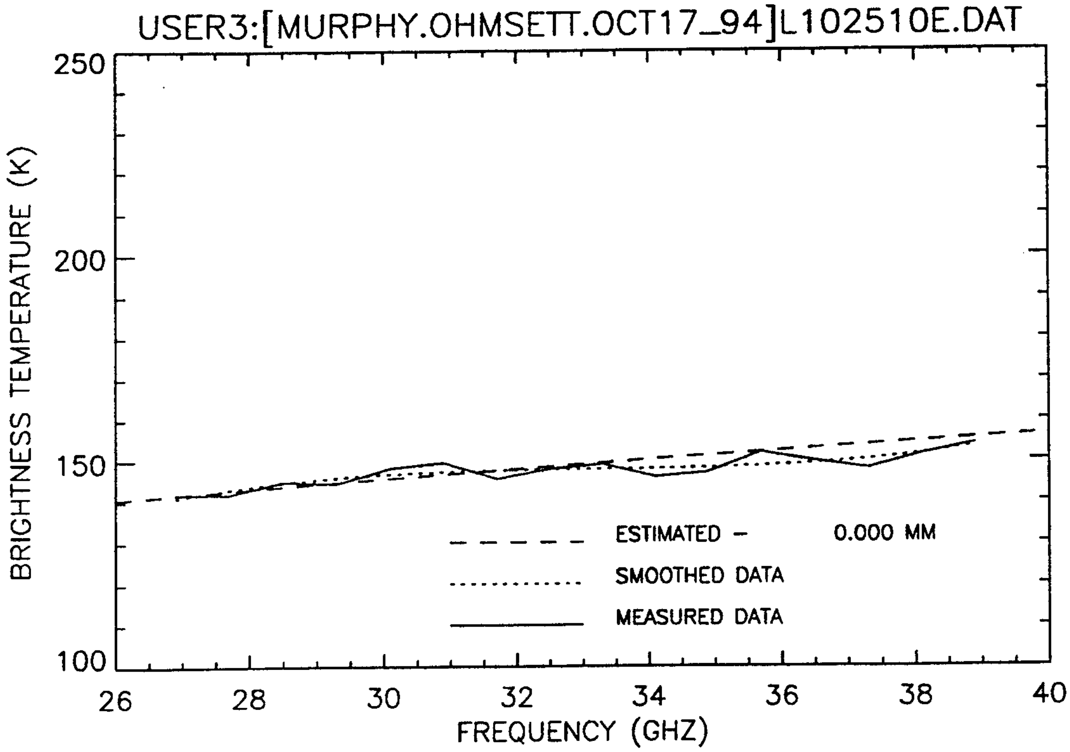

Figure E-11 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, 17 October 1994, Pass 5

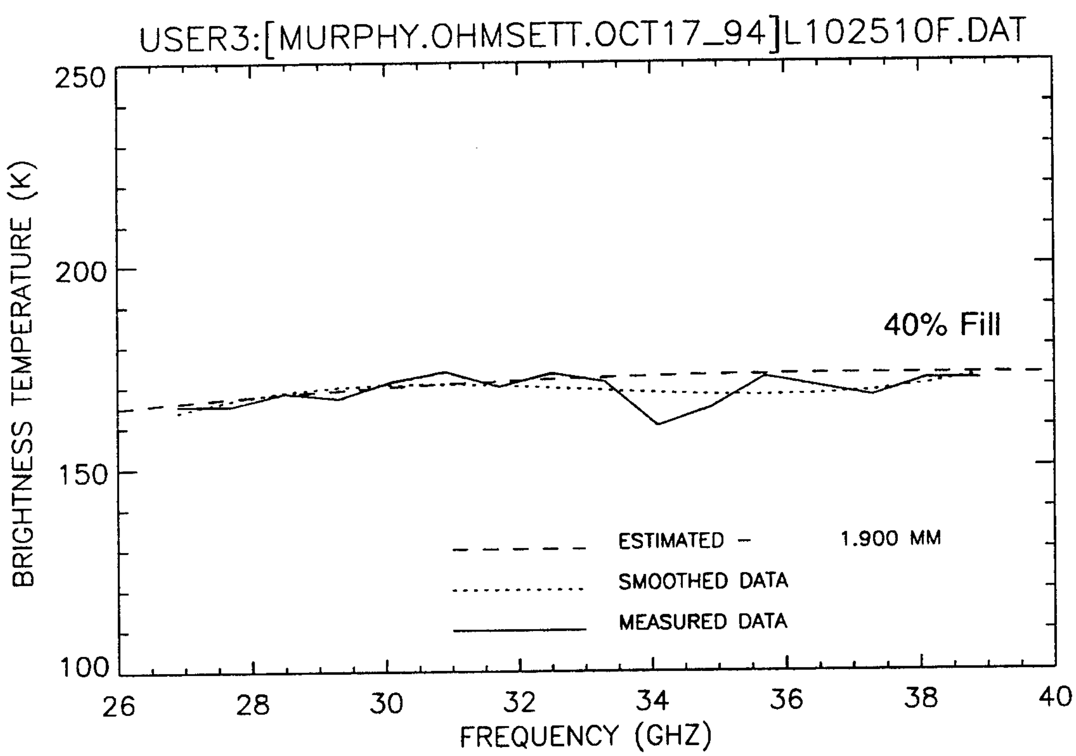

Figure E-12 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, 17 October 1994, Pass 6

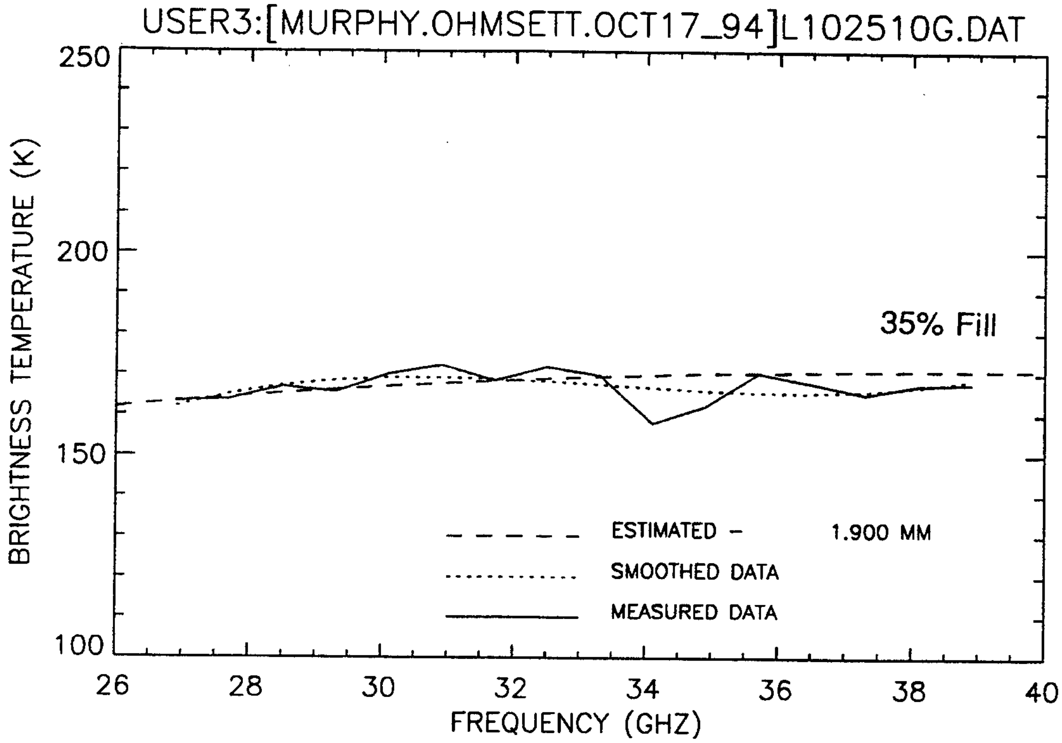

Figure E-13 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, 17 October 1994, Pass 7

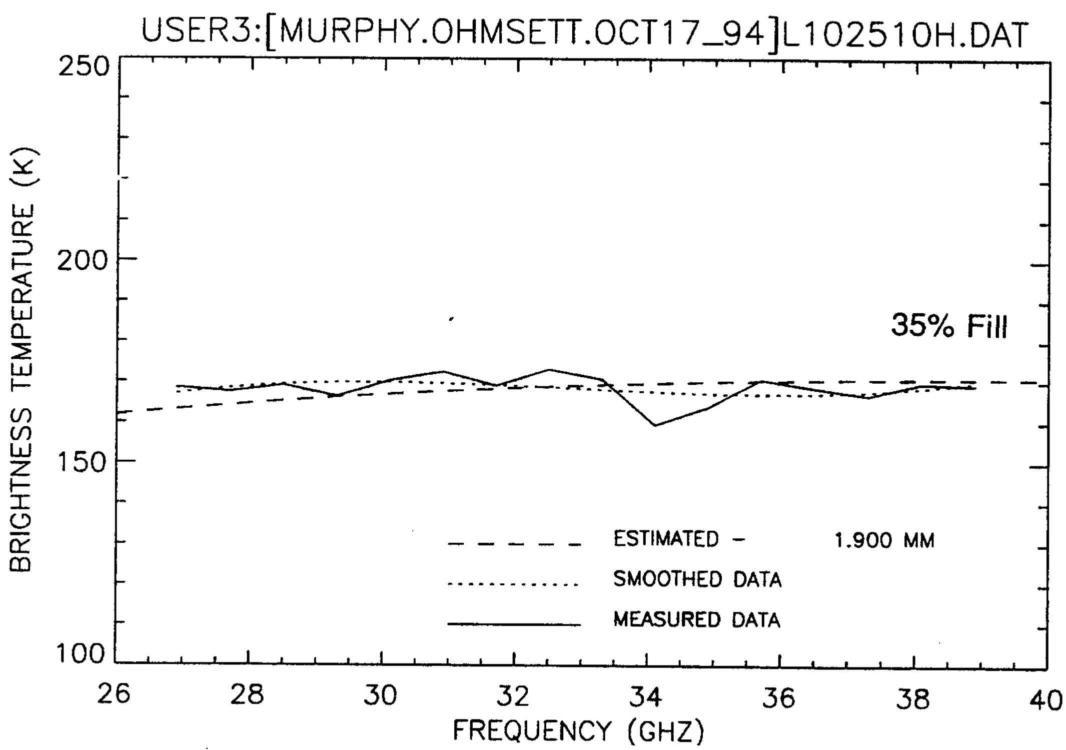

Figure E-14 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, 17 October 1994, Pass 8

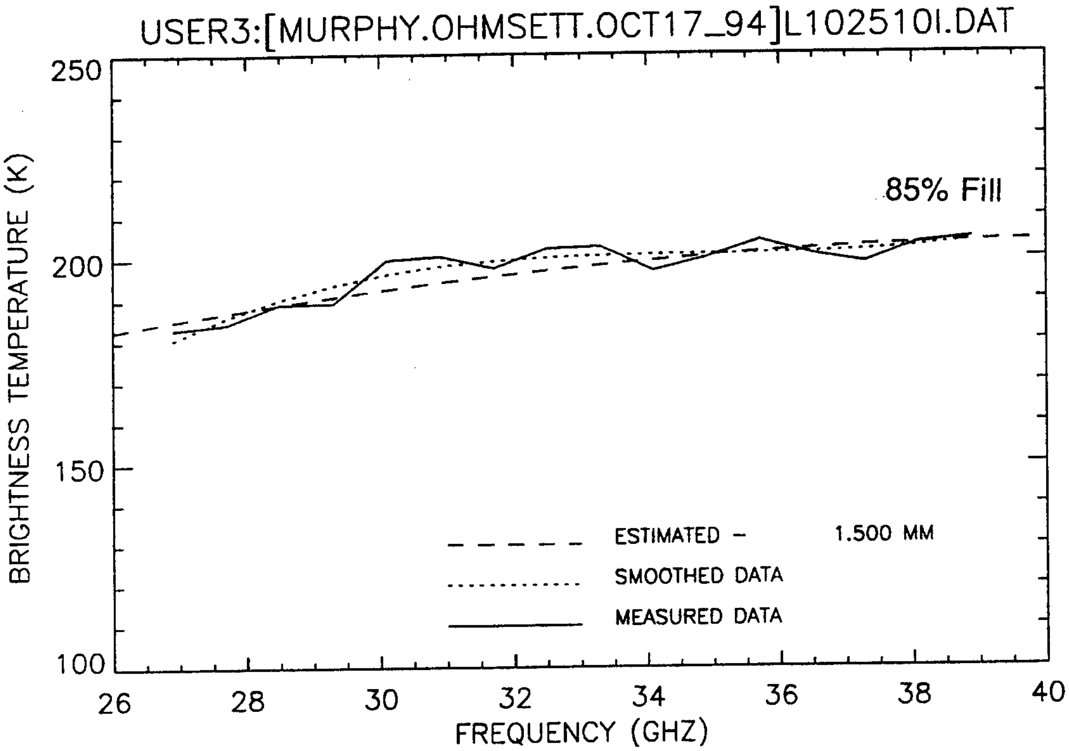

Figure E-15 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, 17 October 1994, Pass 9

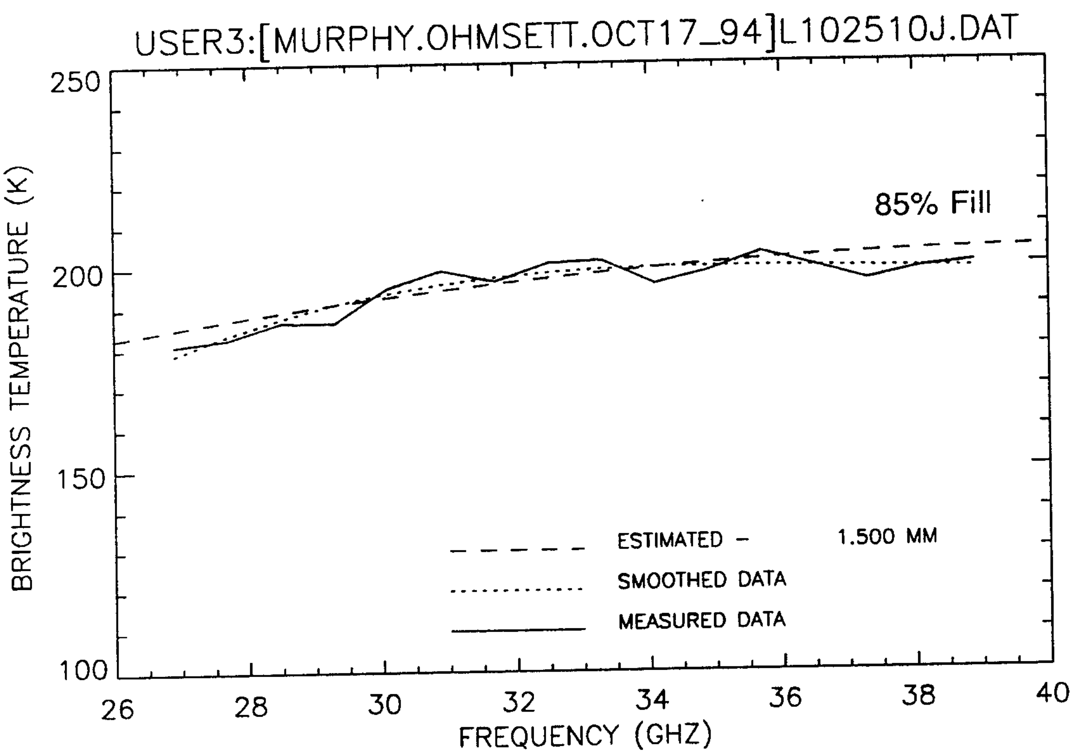

Figure E-16 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, 17 October 1994, Pass 10

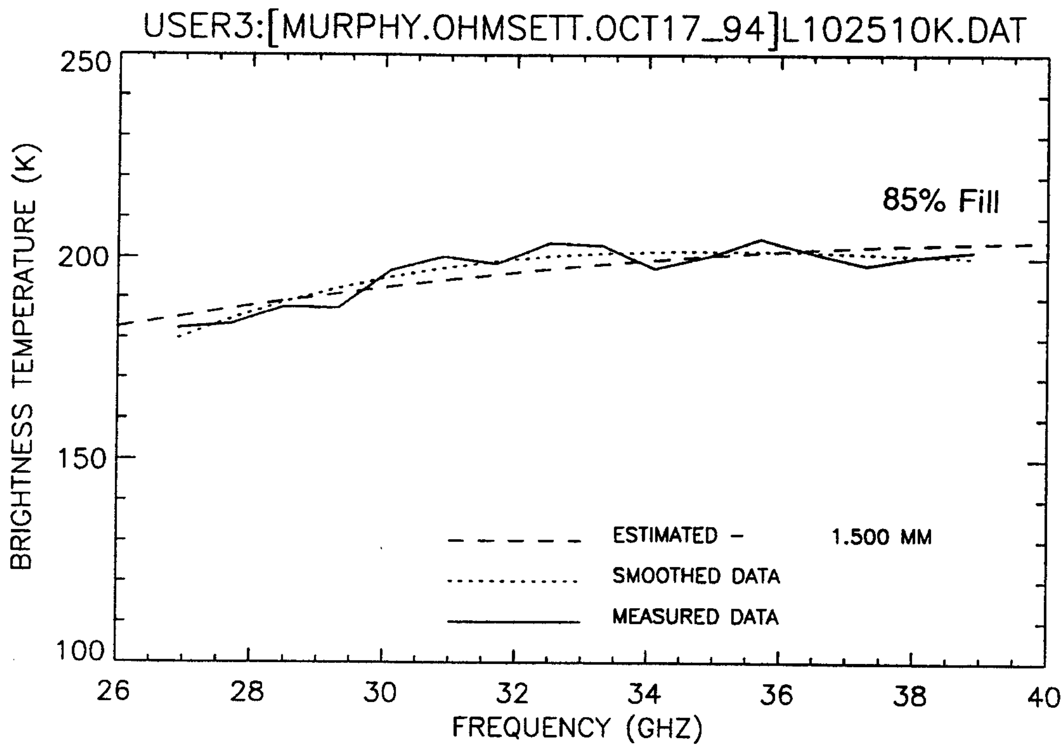

Figure E-17 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, 17 October 1994, Pass 11

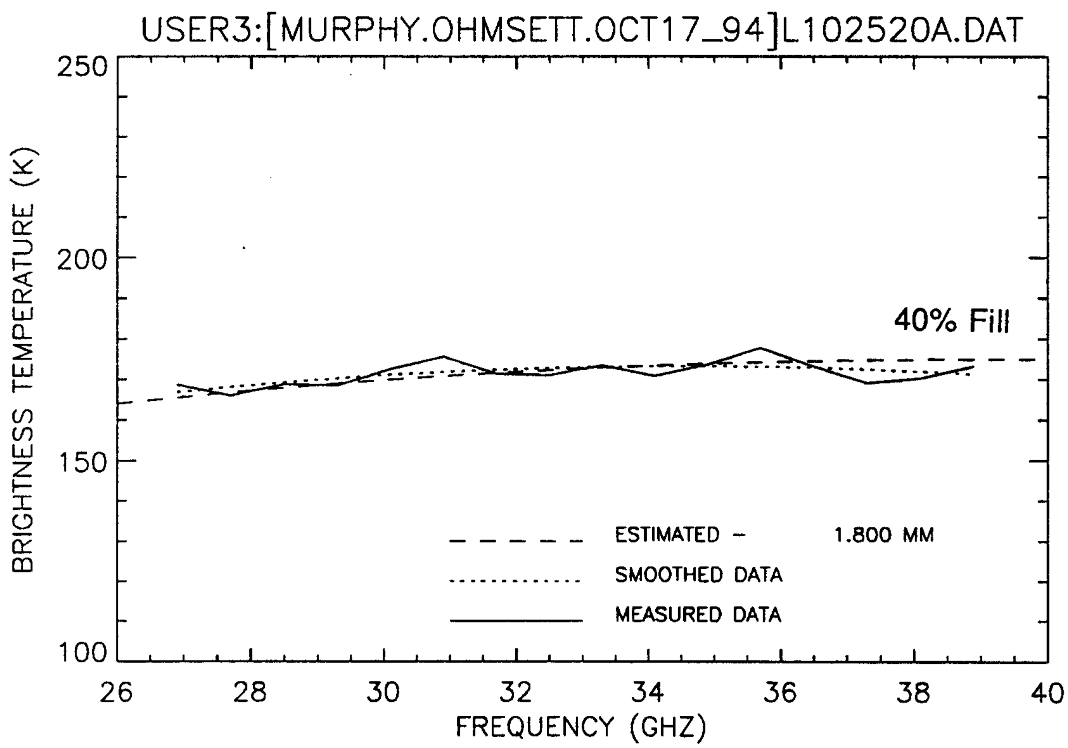

Figure E-18 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 17 October 1994, Pass 1

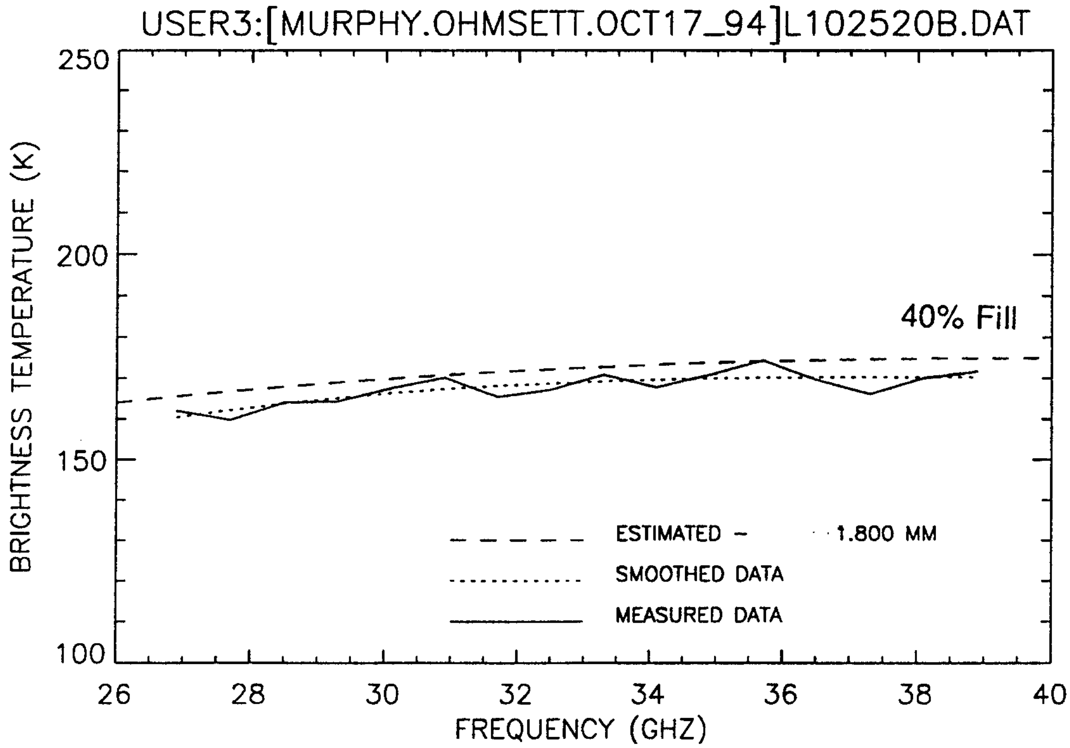

Figure E-19 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 17 October 1994, Pass 2

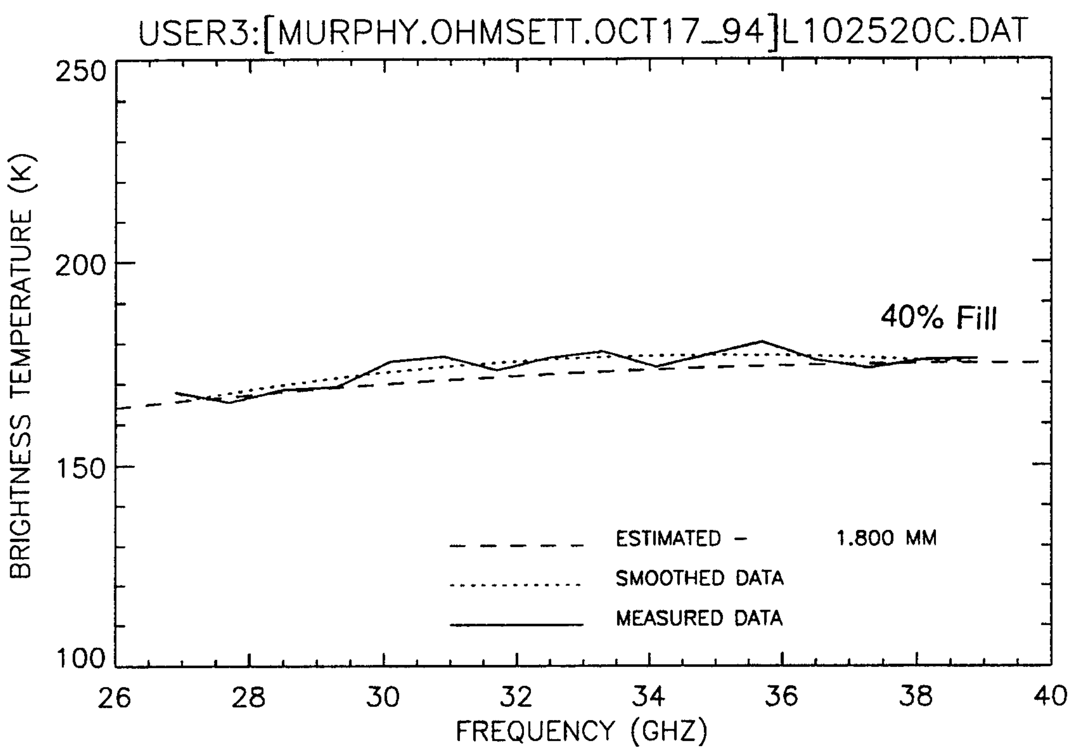

Figure E-20 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 17 October 1994, Pass 3

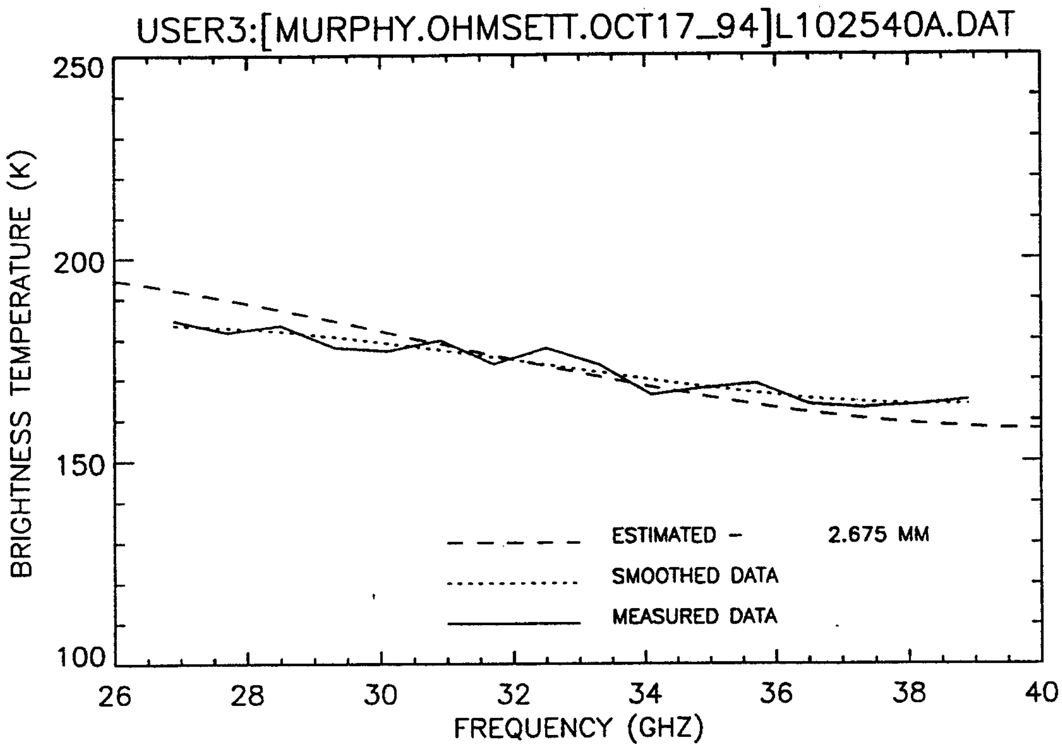

Figure E-21 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 17 October 1994, Pass 1

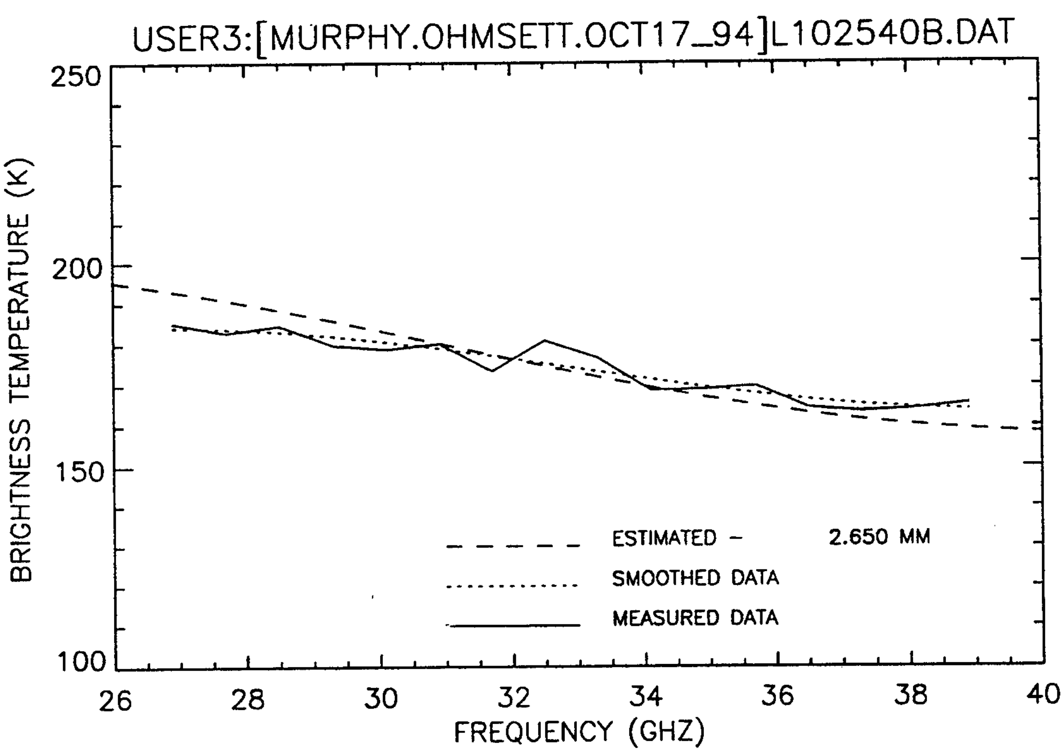

Figure E-22 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 17 October 1994, Pass 2

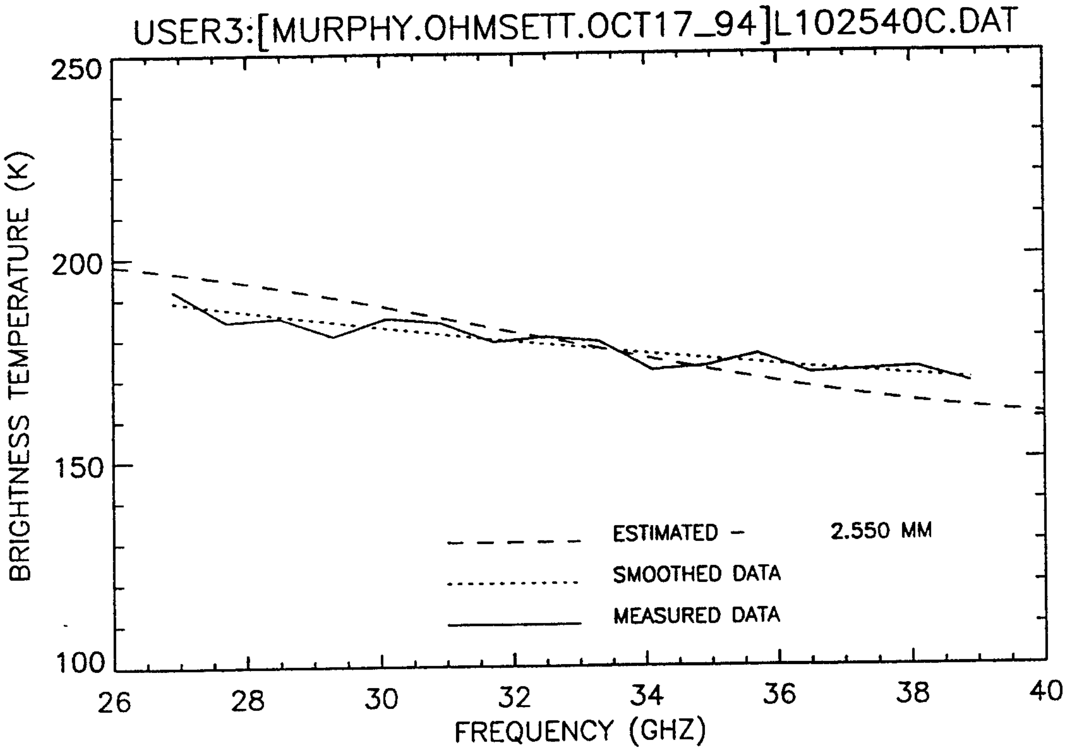

Figure E-23 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 17 October 1994, Pass 3

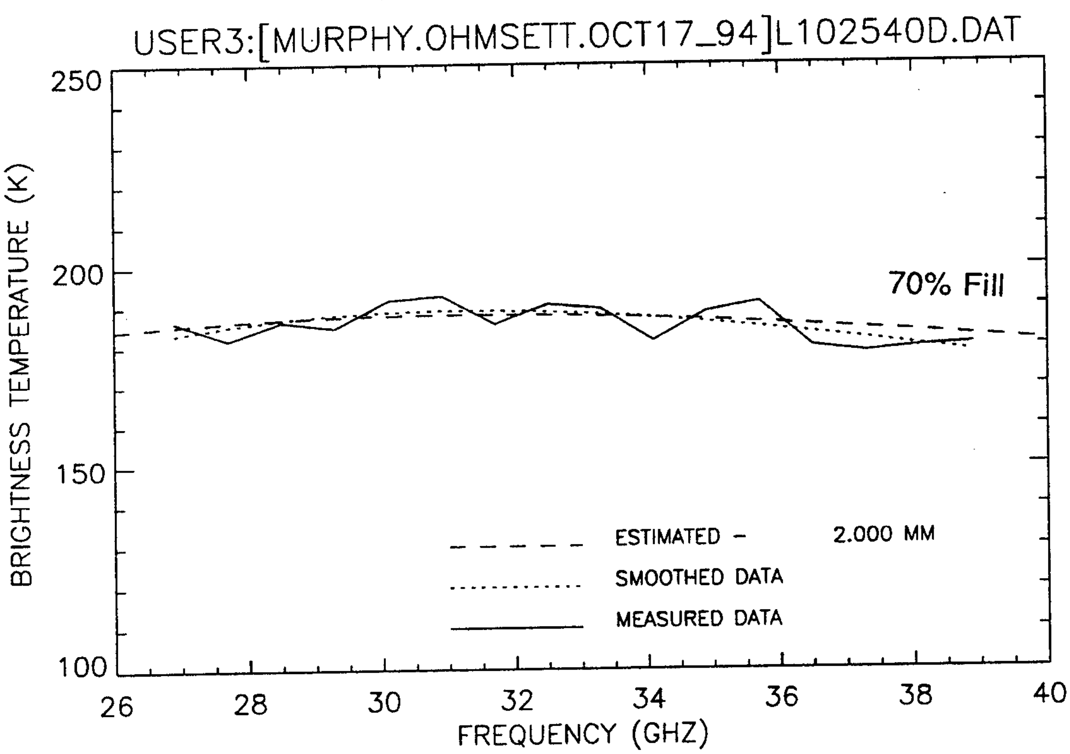

Figure E-24 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 17 October 1994, Pass 4

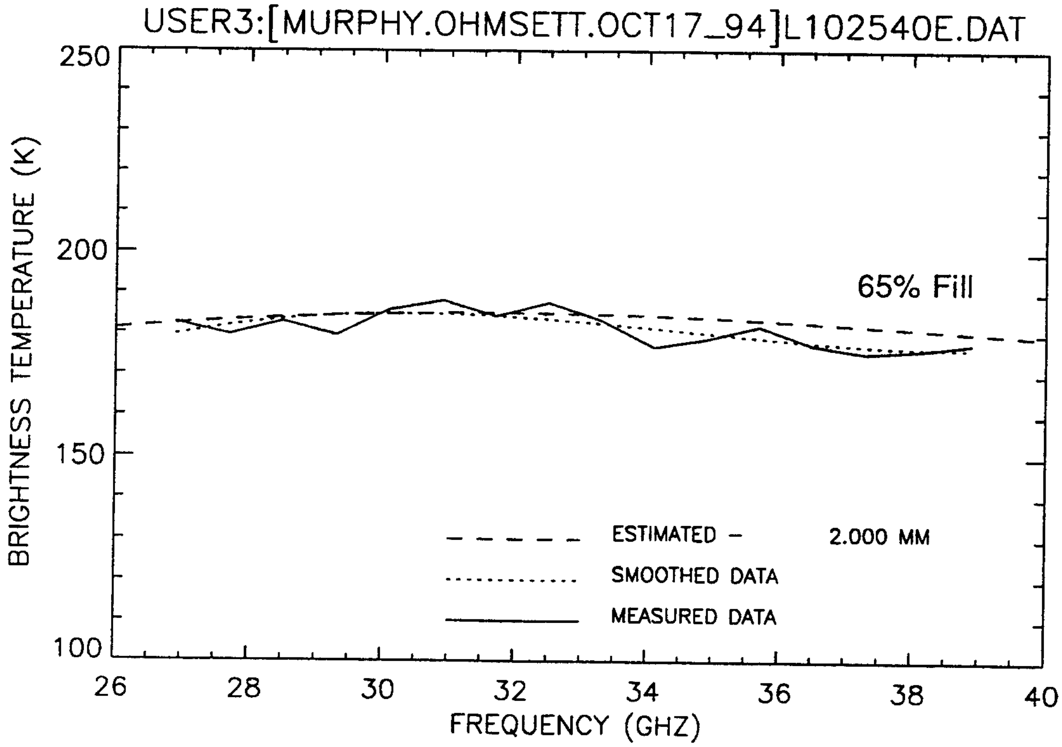

Figure E-25 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 17 October 1994, Pass 5

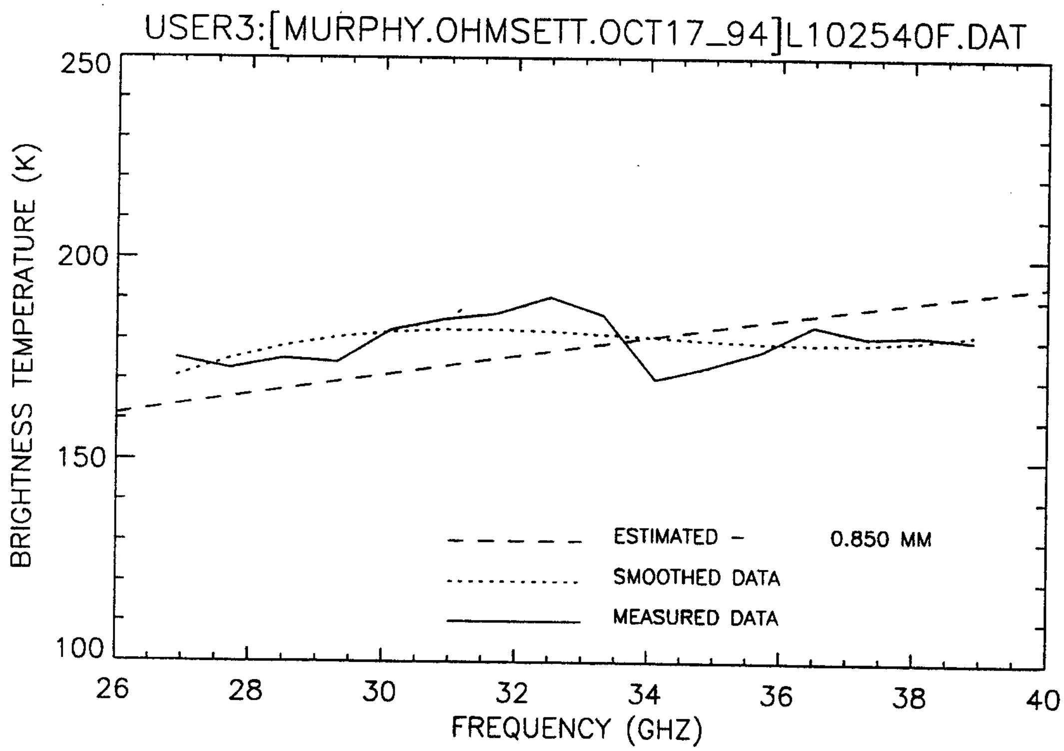

Figure E-26 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 17 October 1994, Pass 6

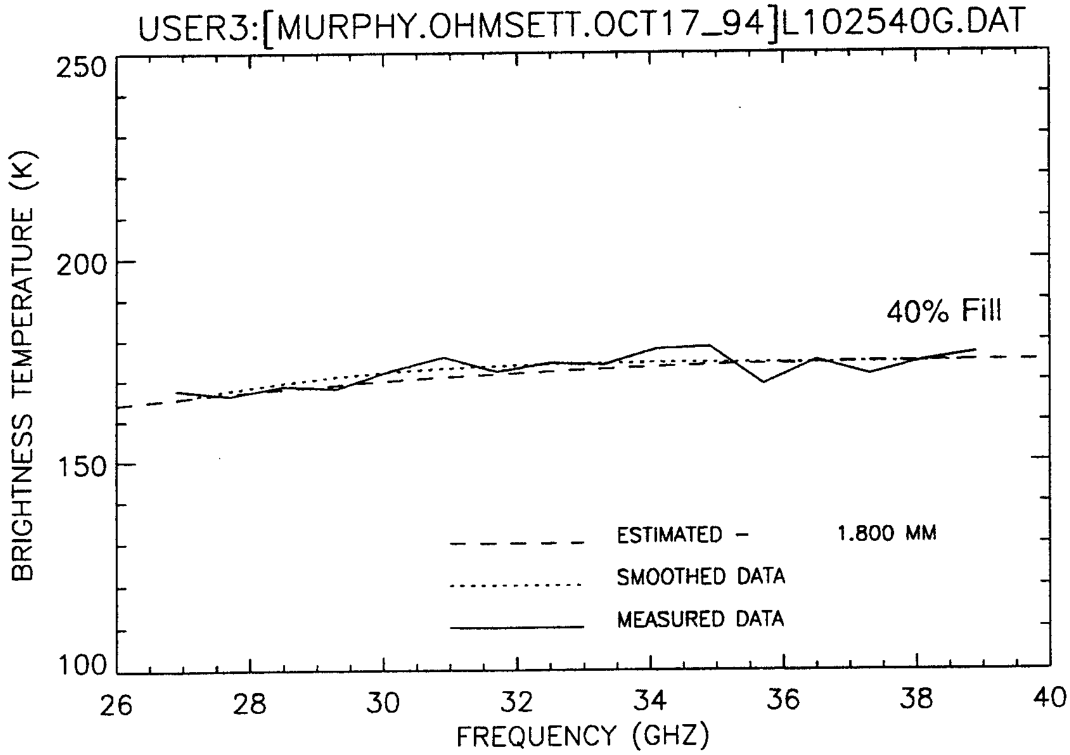

Figure E-27 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 17 October 1994, Pass 7

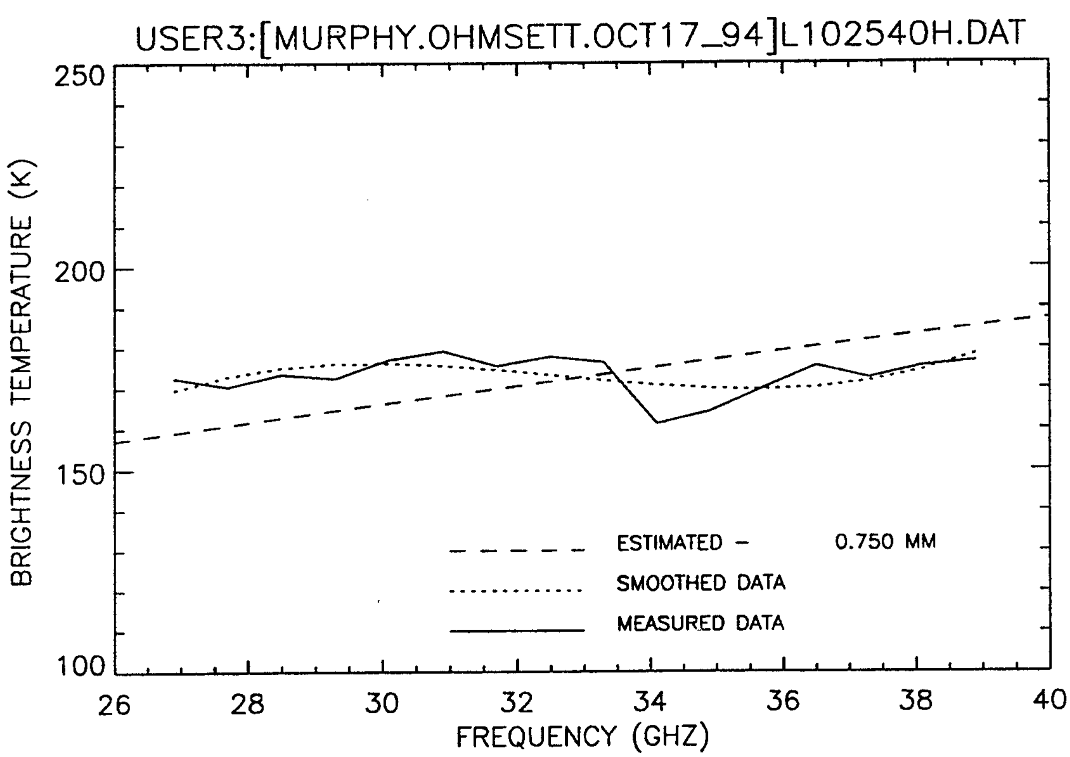

Figure E-28 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 17 October 1994, Pass 8

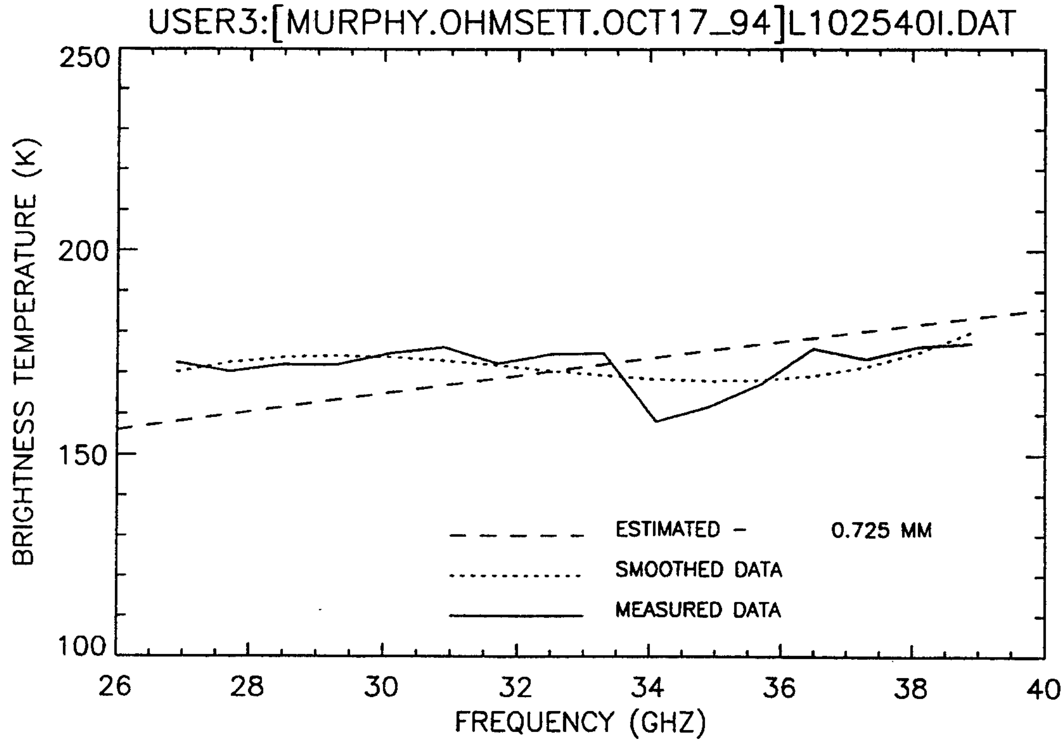

Figure E-29 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 17 October 1994, Pass 9

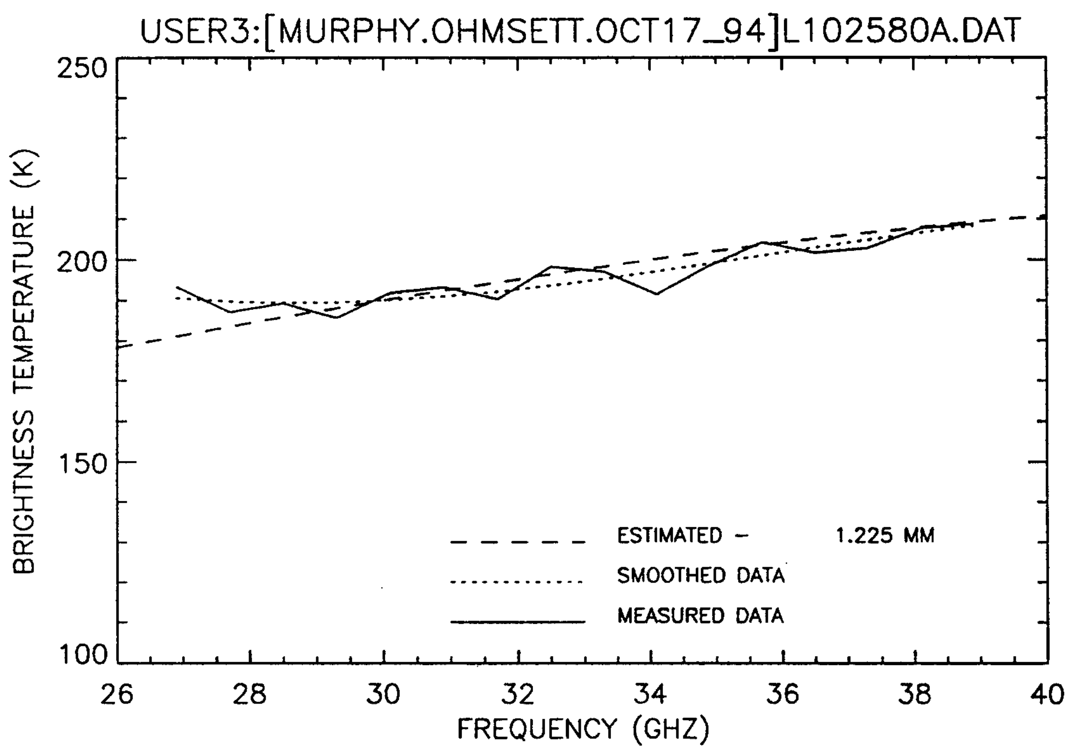

Figure E-30 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, 17 October 1994, Pass 1

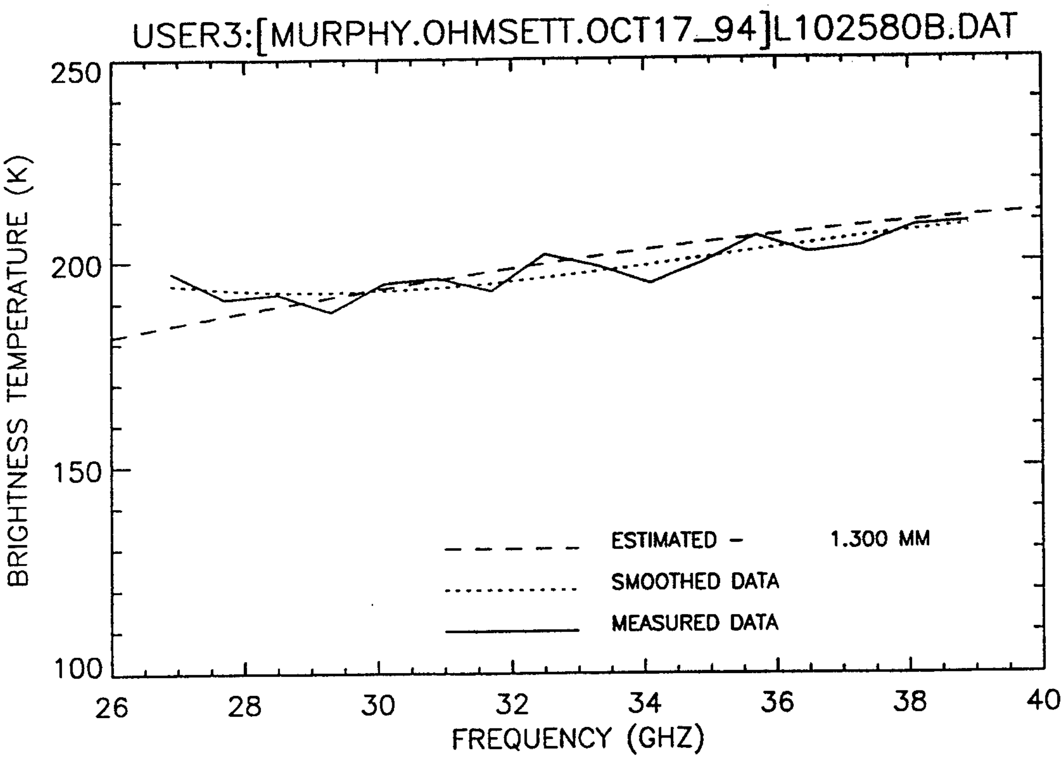

Figure E-31 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, 17 October 1994, Pass 2

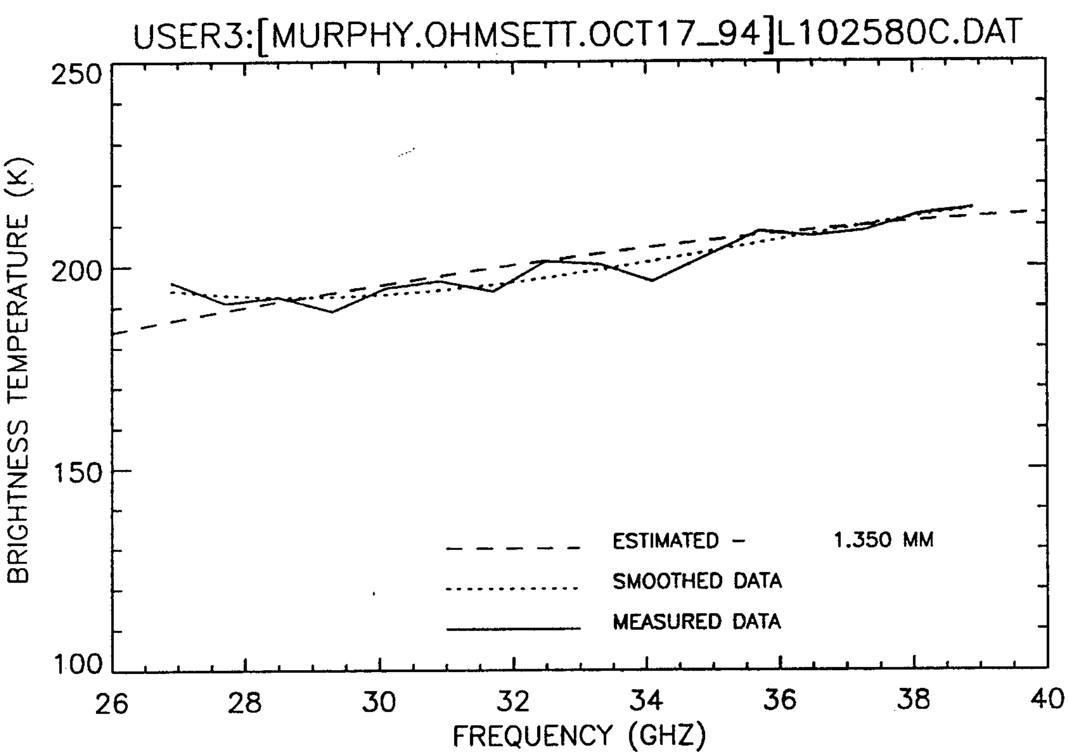

Figure E-32 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, 17 October 1994, Pass 3

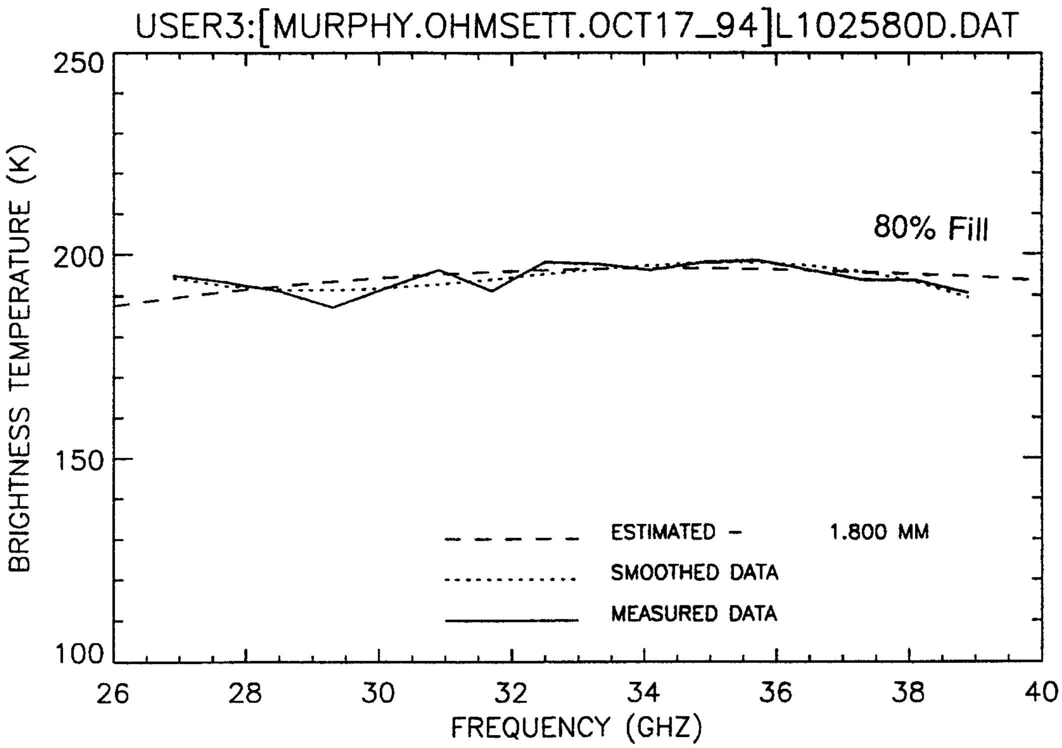

Figure E-33 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, 17 October 1994. Pass 4

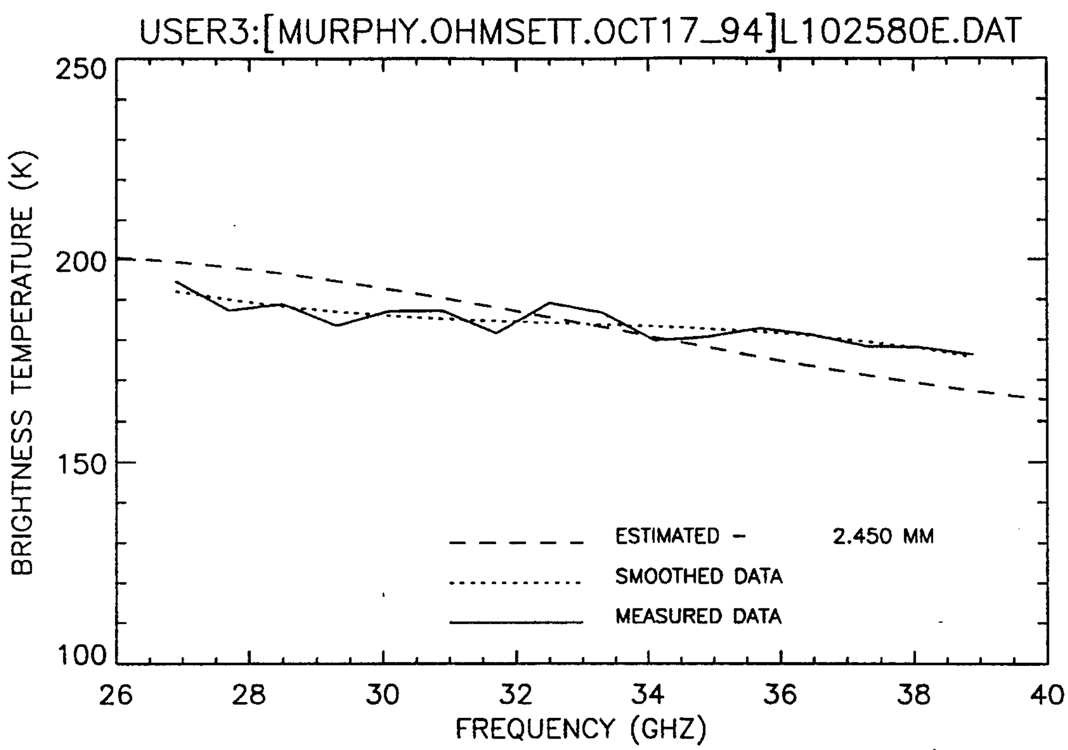

Figure E-34 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, 17 October 1994, Pass 5

The crude oil targets were allowed to remain overnight in the OHMSETT tank to allow evaporation of the light volatile products. The surface of the tank remained calm during this period, and there were no adverse weather conditions that would have disturbed the oil targets.

M180000A - This curve was chosen as the reference water temperature for this data set.

M180000B - This curve is a fair-to-good match to the algorithm estimate of 0.0 mm.

M180000C - This curve is a good match to the algorithm estimate of 0.0 mm.

The OHMSETT main bridge was moved so the FSR could make measurements from the center of the 100% coverage at 2.5 mm oil target pool. This pool contained a uniform oil layer that covered the entire target pool.

M182500A - This curve is a fair-to-good match to the algorithm estimate of 0.725 mm. Some very slight curvature similar to a 3.75 mm (correlation result) estimate is observed; however, the overall T^B is too high and the amplitude modulation is much too low for the curve to match the 3.75 mm estimate.

M182500B - This curve is a fair-to-good match to the algorithm estimate of 0.7 mm. Some very slight curvature similar to a 3.8 mm (correlation result) estimate is observed; however, the overall T^B is too high and the amplitude modulation is much too low for the curve to match the 3.8 mm estimate well.

M182500C - This curve is a fair-to-good match to the algorithm estimate of 0.7 mm. Some very slight curvature similar to a 3.8 mm (correlation result) estimate is observed; however, the overall T^B is too high and the amplitude modulation is much too low for the curve to match the 3.8 mm estimate (plotted).

M182500D - This curve is a fair match to the algorithm estimate of 0.675 mm. Some very slight curvature similar to a 3.8 mm (correlation result) estimate

is observed; however, the overall T^B is too high and the amplitude modulation is much too low for the curve to match the 3.8 mm estimate.

The oil target pool was stirred up using a boat hook. The beam fill ratio of clumpy oil to water in the FSR footprint was approximately 80% after stirring.

M182500E - This curve is a poor overall match to the algorithm estimate of 1.700 mm. The very high temperature indicates the presence of an emulsion . The curve exhibits some very slight curvature similar to a 1.825 mm (correlation result shown on the plot) estimate; however, the overall T^B seems too high. There may be a partial beam fill effect giving the curve some shape for a very low percentage water emulsion.

M182500F - This curve is a poor match to the algorithm estimate of 1.70 mm. The very high overall temperature indicates the presence of an emulsion. There is a very slight curvature similar to a 1.8 mm estimate (correlation result shown on the plot); however, the average overall T^B is too high. This may be a partial beam fill effect for a very low percentage water emulsion.

M182500G - This curve is a poor match to the algorithm estimate of 1.70 mm. The very high overall temperature indicates the presence of an emulsion. There is a very slight curvature similar to a 1.8 mm estimate (correlation result shown on the plot); however, the average overall T^B is too high. This may be a partial beam fill effect for a very low percentage water emulsion.

The OHMSETT main bridge was moved south to a different patchy oil target within the same containment area. The FSR antenna beam fill is approximately 25% oil.

M182500H - This curve is a poor match to the algorithm estimate of 2.175 mm. There is a very slight curvature similar to a 1.8 mm estimate (correlation result); however, the average overall T^B is too high. Using a partial beam

fill of 80% with a 1.85 mm thickness (plotted) produced an excellent match.

M182500I - This curve is a good match to the algorithm estimate of 1.9 mm.

The OHMSETT bridge was moved to the north end of the target pool to get a greater antenna beam fill. Beam fill is estimated to be approximately 90% oil.

M182500J - This curve is a poor match to the algorithm estimate of 1.675 mm. The very high overall temperature indicates an emulsion.

M182500K - This curve is a poor overall match to the algorithm estimate of 1.7 mm. The very high overall temperature indicates an emulsion. Some slight curvature similar to a 1.7 mm estimate is observed; however, overall T^B too high. The slight curvature may be due to a partial beam fill effect for a very low percentage water emulsion.

The OHMSETT main bridge was moved to the crude oil target containing a volume of oil capable of covering 20% of the pool area with a 2.5 mm uniform oil thickness. The following measurements are from an area containing what appears to be a uniform thickness oil film with an antenna beam fill of 90%.

M182520A - This curve is a fair match to the algorithm estimate of 0.825 mm. The correlation result of 1.55 mm seems to match the shape better, but the overall T^B of the measurement is too low. Using a partial beam fill of 60% with a 1.4 mm thickness (plotted) produced a good match.

M182520B - This curve is a fair match to the algorithm estimate of 0.85 mm. A 1.6 mm estimate seems to match the shape better, but the overall T^B of the measurement is too low. Using a partial beam fill of 60% with a 1.4 mm thickness (plotted) produced an excellent match.

M182520C - This curve is a fair match to the algorithm estimate of 0.9 mm. The correlation result, 1.6 mm, matches the shape better, but the overall T^B of the measurement is too low. Using a partial beam fill of 60% with a 1.4 mm thickness (plotted) produced an excellent match.

The OHMSETT bridge was moved to the south end of the pool which contained scattered oil patches and small blobs of oil. The antenna beam fill is estimated to be 20% oil.

M182520D - This curve is a good match to the algorithm estimate of 0.5 mm.

M182520E - This curve is a fair match to the algorithm estimate of 0.4 mm, although the slight curve shape doesn't seem to match known T^B measurements.

The oil target area was stirred to create a more uniform distribution of patchy oil in the FSR antenna beam; the beam fill for the following measurements is approximately 60%.

M182520F - This curve is a poor match to the algorithm estimate of 1.9 mm. The slight curve shape might fit a 4.9 mm (plotted) estimate; however, the amplitude modulation of T^B is much too low. The result is inconclusive.

M182520G - This curve is a poor match to the algorithm estimate of 1.9 mm. The slight curve shape looks like it could match a 3.5 mm estimate; however the overall T^B is too high and does not exhibit sufficient amplitude modulation. The result is inconclusive.

M182520H - This curve is a good match to the algorithm estimate of 1.75 mm.

The main bridge was moved north to observe small tar balls; the FSR antenna had an approximate 20% oil beam fill.

M182520I - This curve is a fair-to-good match to the algorithm estimate of 0.65 mm. The slight curve shape could possibly match a 1.6 mm estimate.

M182520J - This curve is a good match to the algorithm estimate of 0.55 mm.

The main bridge was moved north again; the FSR antenna had a 25% beam fill.

M182520K - This curve is a fair-to-good match to the algorithm estimate of 0.425 mm.

M182520L - This curve is a good-to-excellent match to the algorithm estimate of 0.5 mm.

The OHMSETT main bridge was moved to a new oil target pool, 40% intended coverage at a 2.5 mm thickness. For the following measurements, the FSR antenna footprint was over an area that contained a uniform thickness of oil.

M182540A - This curve is a poor match to the algorithm estimate of 2.35 mm. The curve shape is more representative of a 2.0 mm estimate (the correlation result shown on the plot), although the overall T^B of the measurement seems too low. Using a partial beam fill of 80% with a 2.1 mm thickness (plotted) produced an excellent match.

M182540B - This curve is a poor match to the algorithm estimate of 2.25 mm. The curve shape is more representative of a 2.0 mm estimate, although the overall T^B of the measurement seems too low. Using a partial beam fill of 85% with a 2.1 mm thickness (plotted) produced an excellent match.

M182540C - This curve is a poor match to the algorithm estimate of 2.25 mm. The curve shape is more representative of a 2.0 mm estimate, although the overall T^B of the measurement seems too low. Using a partial beam fill of 85% with a 2.1 mm thickness (plotted) produced an excellent match.

The oil was stirred to create areas of patchy oil. The FSR had approximately 30% antenna beam fill.

M182540D - This curve is a poor match to the algorithm estimate of 0.725 mm. Using a partial beam fill of 40% with a 1.8 mm thickness (plotted) produced an excellent match.

M182540E - This curve is a poor-to-fair match to the algorithm estimate of 0.675 mm. Using a partial beam fill of 35% with a 1.8 mm thickness (plotted) produced an excellent match.

The main bridge was moved 2 - 3 feet north. The FSR antenna beam fill was estimated to be 20%.

M182540F - This curve is a fair match to the algorithm estimate of 0.975 mm; however, using a partial beam fill of 65% with a 1.5 mm thickness (plotted) produced an excellent match.

M182540G - This curve is a poor-to-fair match to the algorithm estimate of 0.950 mm. Using a partial beam fill of 65% with a 1.5 mm thickness (plotted) produced an excellent match.

The main bridge was moved north so that the FSR could measure near the north edge of the containment boom. The FSR antenna beam fill is estimated to be 60%.

M182540H - This curve is a poor match to the algorithm estimate of 2.0 mm. The curve shape is similar to a 7.7 mm estimate; however, the modulation is on the same order of magnitude as the noise fluctuation and is probably not significant. The result is inconclusive.

M182540I - This curve is a poor match to the algorithm estimate of 2.050 mm. The curve shape is similar to a 7.5 mm estimate; however, the modulation is on the same order of magnitude as the noise fluctuation and is probably not significant. The result is inconclusive; however, based on these two measurements, the T^B modulation may have occurred because the oil pooled next to the containment boom, creating a small region that really was 7.5 - 7.7 mm thick. The containment boom itself may also have affected the measurements.

The OHMSETT main bridge was moved to measure a new oil target pool containing the volume of oil necessary to cover 80% of the surface of the pool with 2.5 mm thick oil. The FSR antenna was set to measure a uniform oil thickness (100% antenna beam fill).

M182580A - This curve is a poor match to the algorithm estimate of 2.55 mm. The curve shape is more similar to the correlation result of 2.9 mm, although overall the T^B and amplitude modulation seem too low.

M182580B - This curve is a poor match to the algorithm estimate of 2.525 mm. The curve shape is more similar to the correlation result of 6.0 mm, although overall the T^B and amplitude modulation seem too low.

M182580C - This curve is a poor match to the algorithm estimate of 2.4 mm. The curve shape is very flat. The result is inconclusive.

The main bridge was moved south. The oil target pool was stirred to create areas of patchy oil. The FSR antenna beam fill was estimated to be 60%.

M182580D - This curve is a poor match to the algorithm estimate of 1.675 mm. This measurement appears to have characteristics of an emulsion curve shape. There appears to be a small shape characteristic similar to an 8.0 mm estimate although the T^B match and amplitude modulation are too low and probably not significant.

M182580E - This curve is a poor match to the algorithm estimate of 1.675 mm. This measurement appears to have characteristics of an emulsion curve shape. There appears to be a small shape characteristic similar to an 8.2 mm estimate, although the T^B match and amplitude modulation are too low and probably not significant.

M182580F - This curve is a poor match to the algorithm estimate of 1.675 mm. This measurement appears to have characteristics of an emulsion curve shape. There appears to be a small shape characteristic similar to an 8.2 mm estimate, although the T^B match and amplitude modulation are too low and probably not significant.

The main bridge was moved north. The area for FSR measurements contained approximately 50% beam fill.

M182580G - This curve is a poor match to the algorithm estimate of 1.8 mm; however, the curve is similar in shape. Using a partial beam fill of 90% with the 1.8 mm thickness (plotted) produced an excellent match.

M182580H - This curve is a poor match to the algorithm estimate of 1.225 mm. Using a partial beam fill of 85% with a 1.8 mm thickness (plotted) produced an excellent match.

The OHMSETT main bridge was moved to a new oil target pool containing a volume of oil intended to create a 2.5 mm oil thickness over 10% of the pool surface.

M18BASEA - This curve is a poor match to the algorithm estimate of 1.15 mm. Using a partial beam fill of 80% with a 1.8 mm thickness (plotted) produced an excellent match.

M18BASEB -This curve is a poor-to-fair match to the algorithm estimate of 1.325 mm. Using a partial beam fill of 90% with a 1.8 mm thickness (plotted) produced an excellent match.

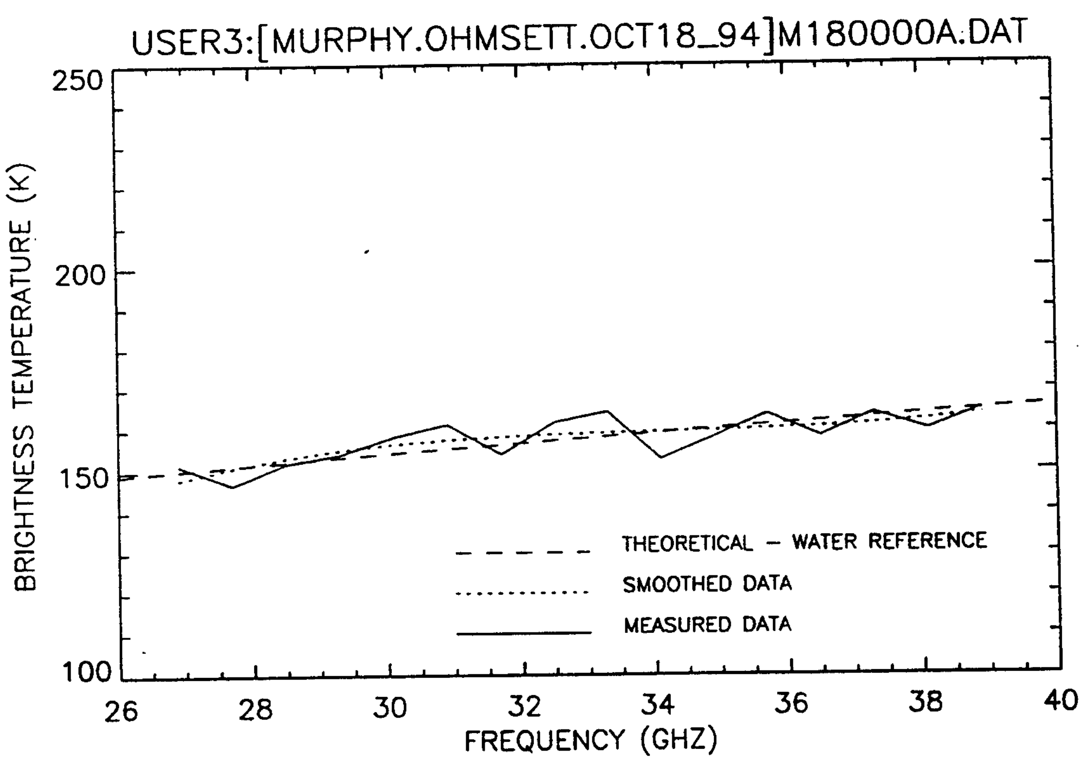

Figure E-35 T^B Versus Frequency Plot for Background Water, 18 October 1994, Pass 1

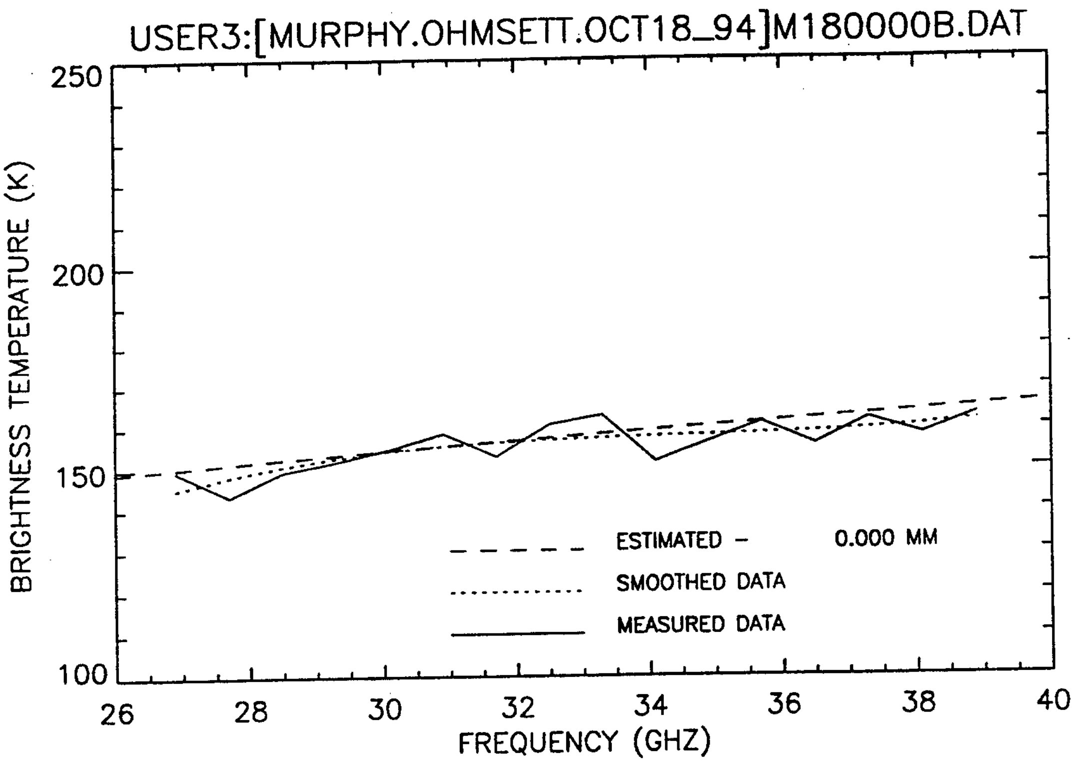

Figure E-36 T^B Versus Frequency Plot for Background Water, 18 October 1994, Pass 2

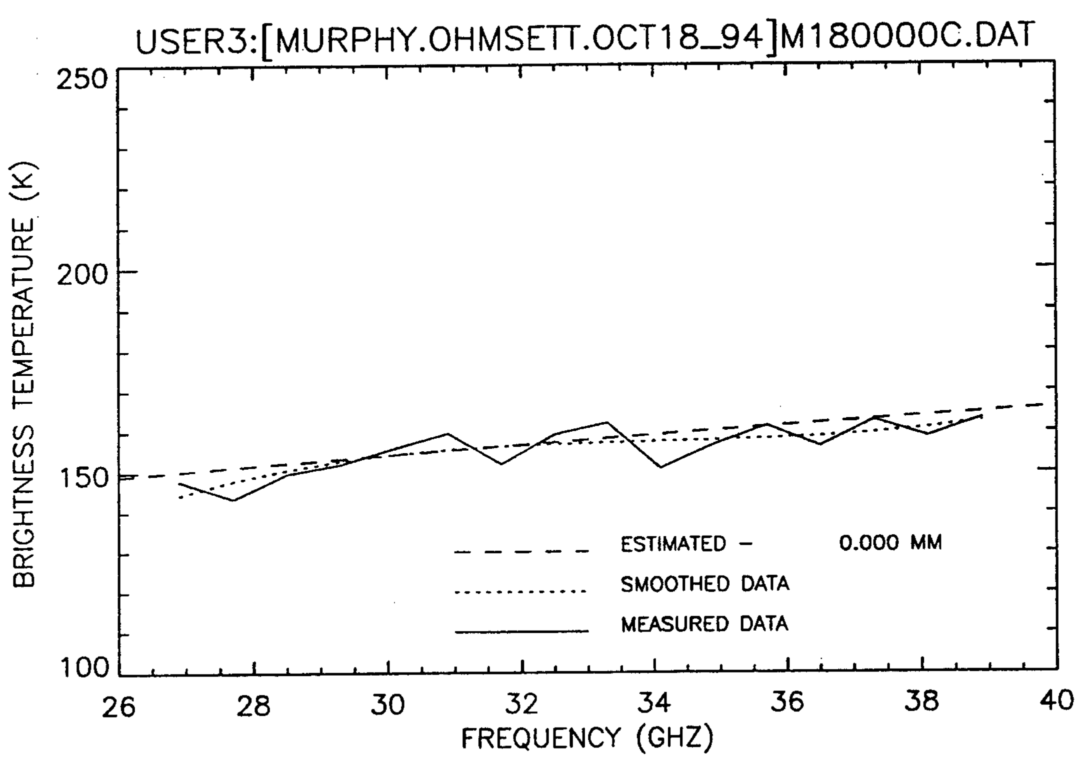

Figure E-37 T^B Versus Frequency Plot for Background Water, 18 October 1994, Pass 3

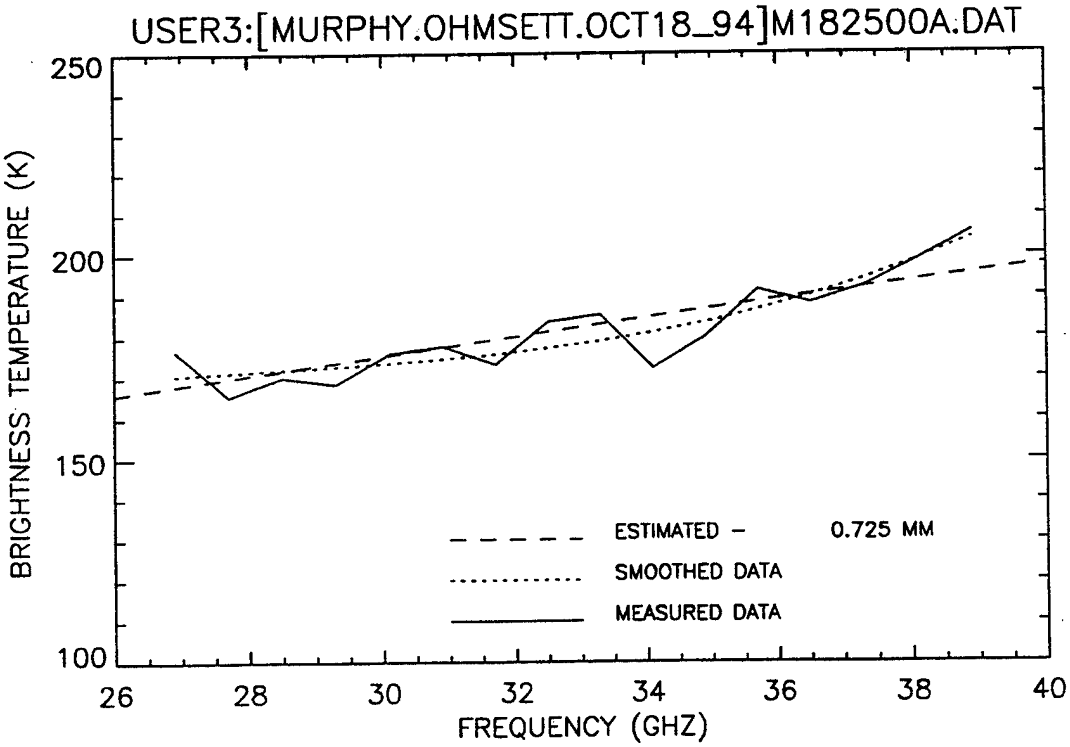

Figure E-38 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, 18 October 1994, Pass 1

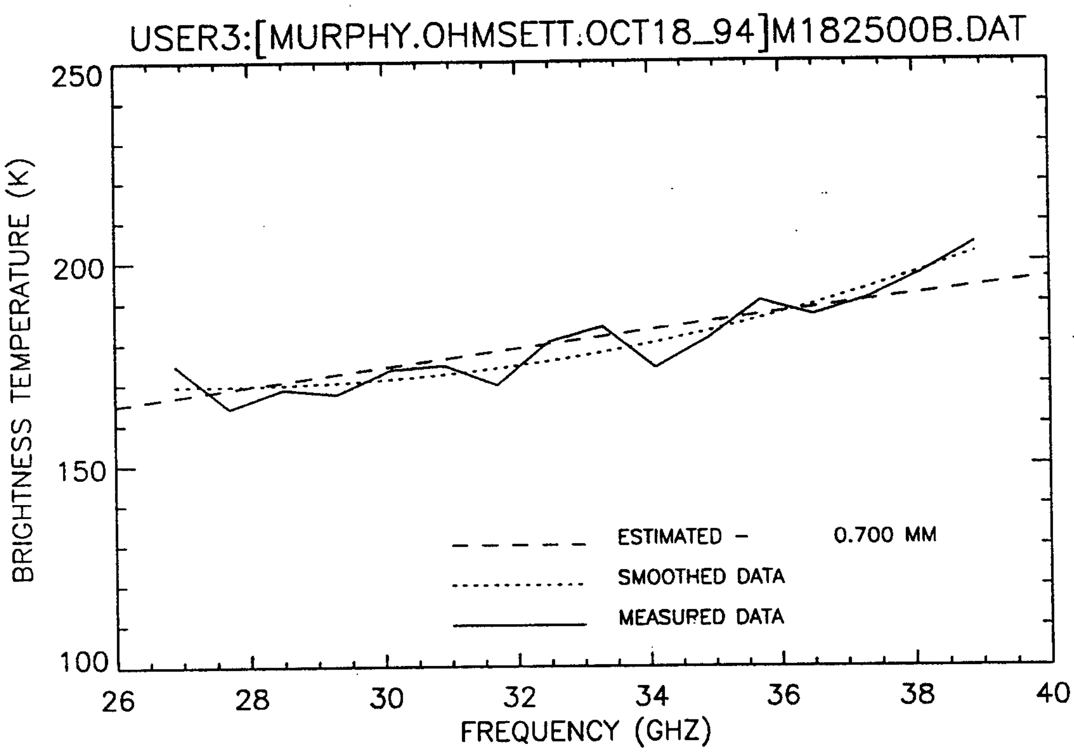

Figure E-39 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, 18 October 1994, Pass 2

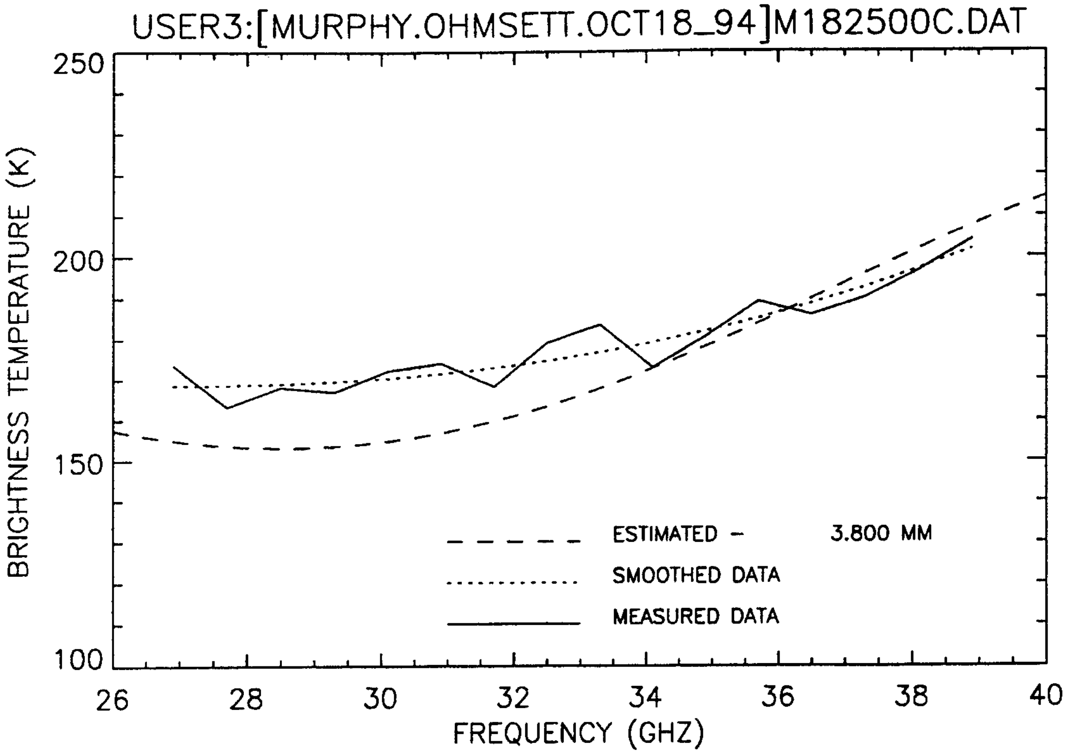

Figure E-40 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, 18 October 1994, Pass 3

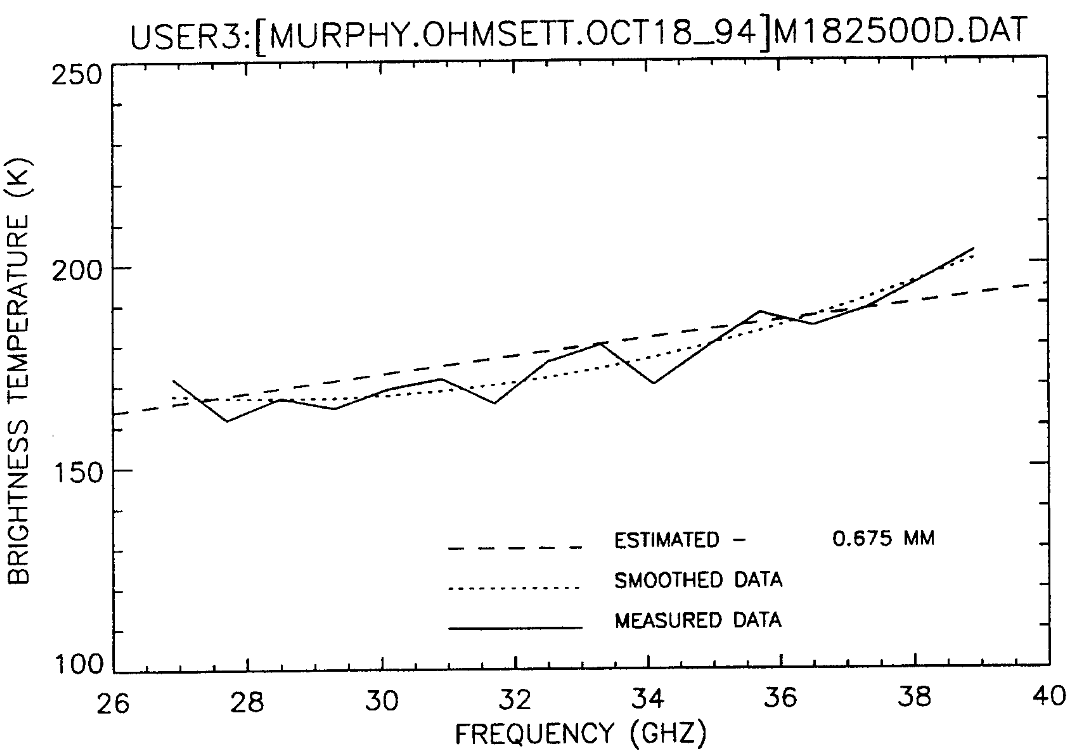

Figure E-41 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, 18 October 1994, Pass 4

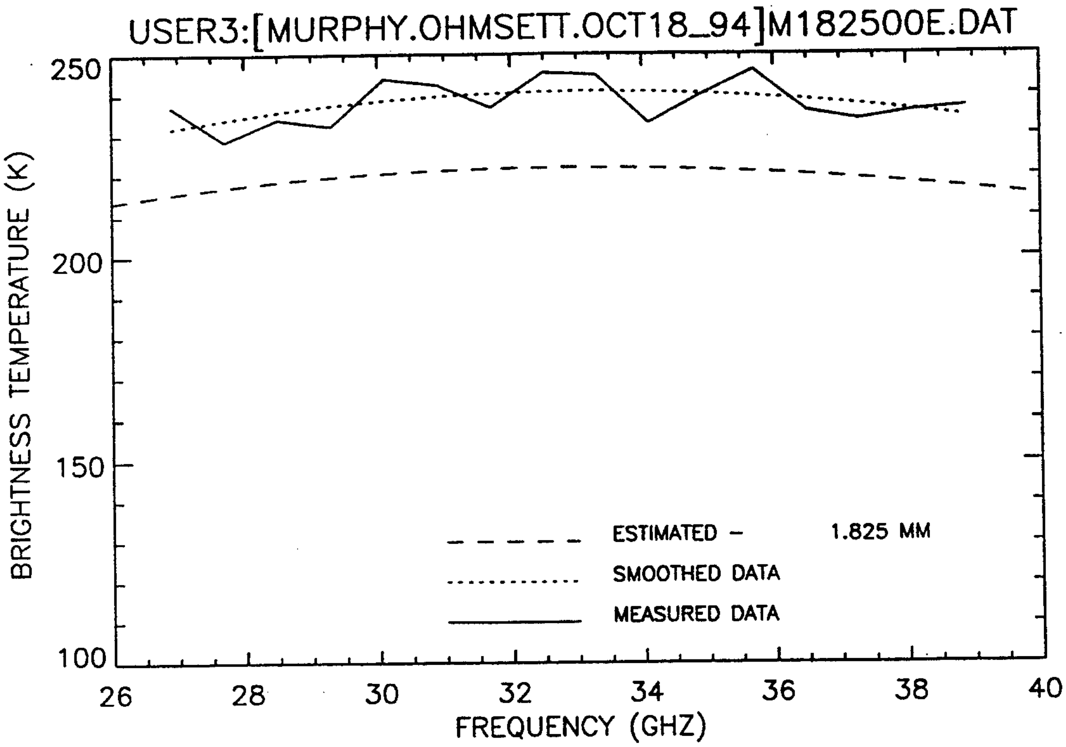

Figure E-42 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 5

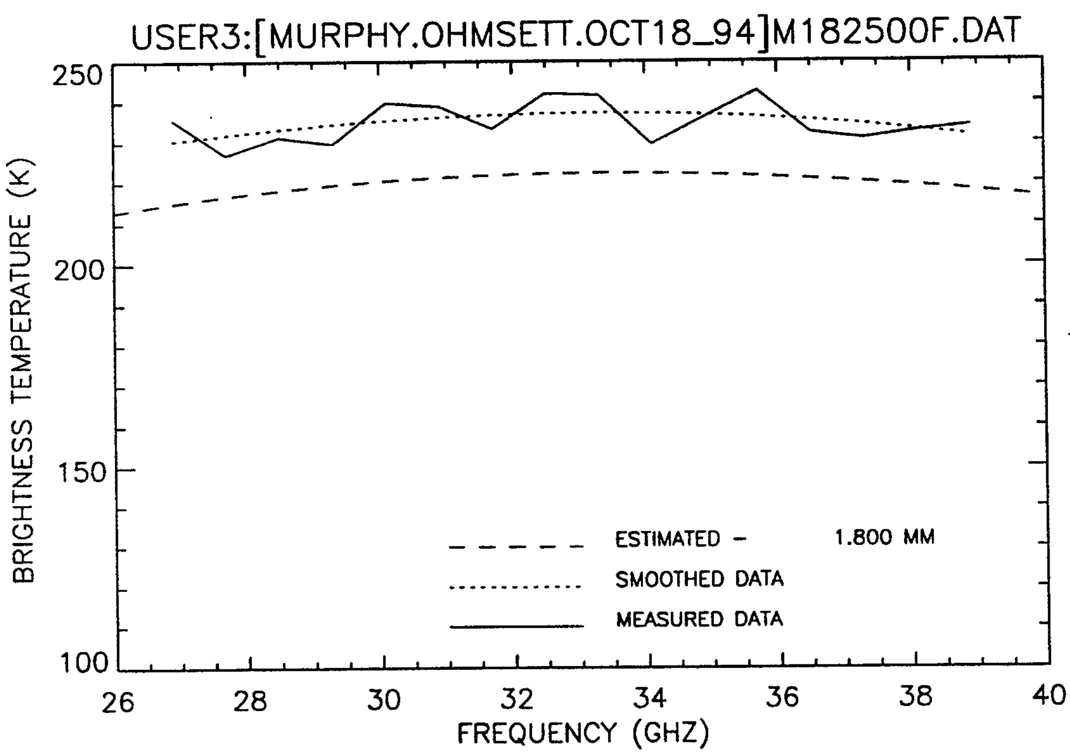

Figure E-43 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 6

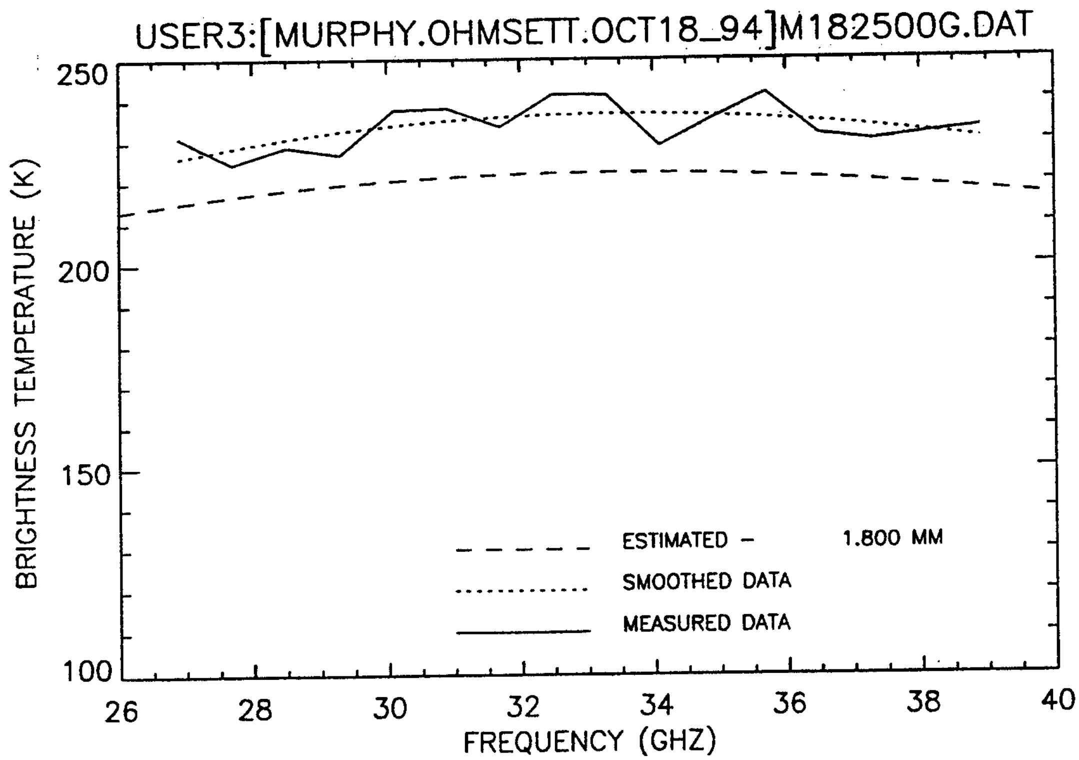

Figure E-44 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 7

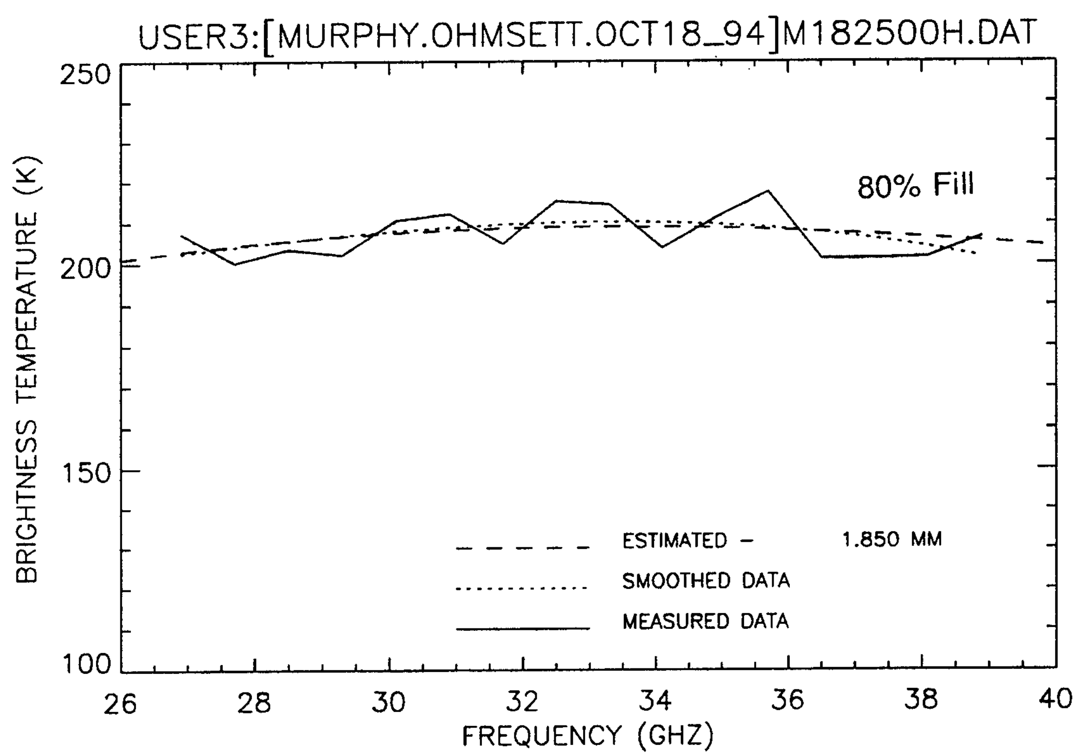

Figure E-45 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 8

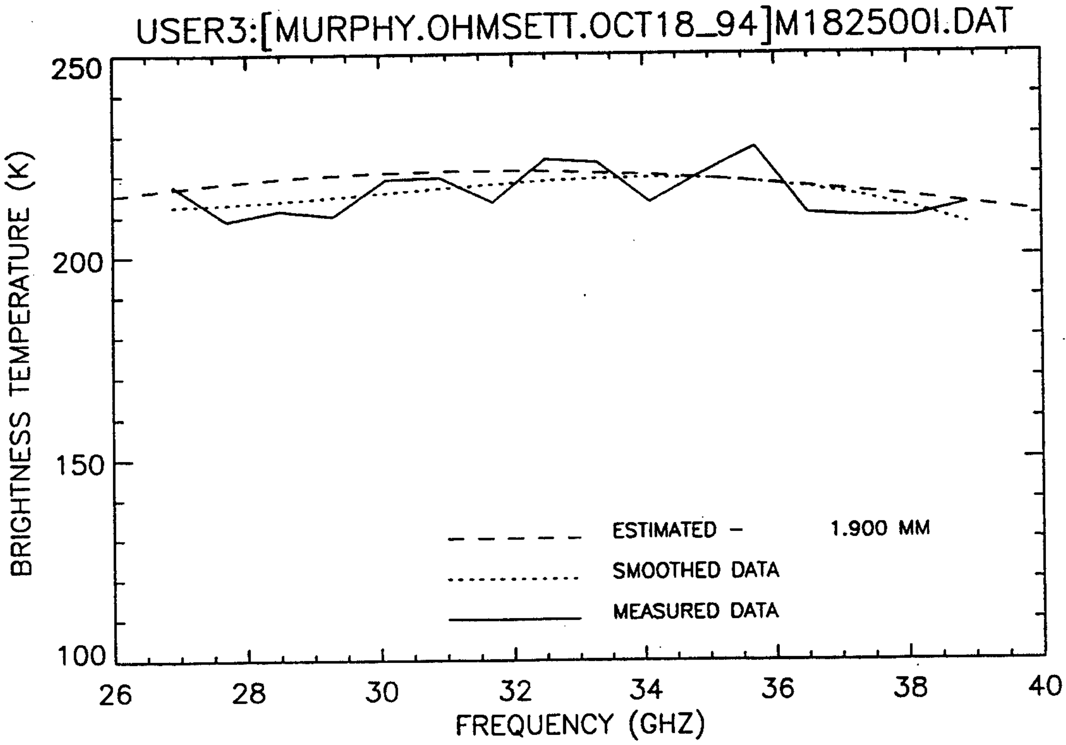

Figure E-46 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 9

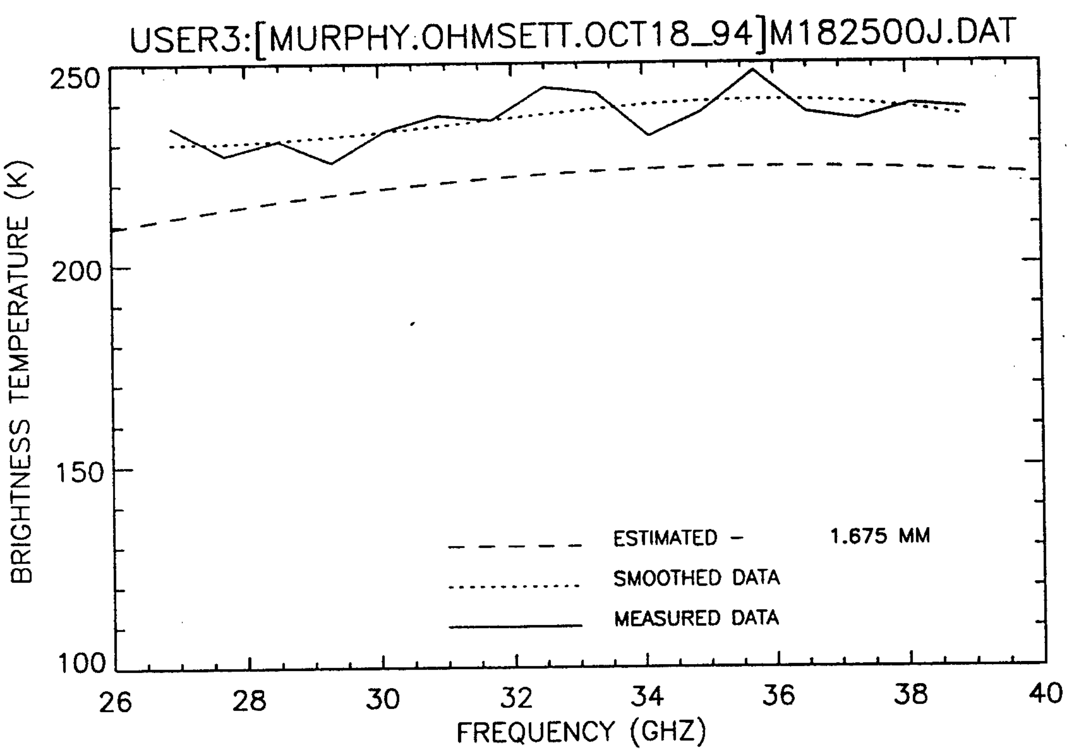

Figure E-47 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 10

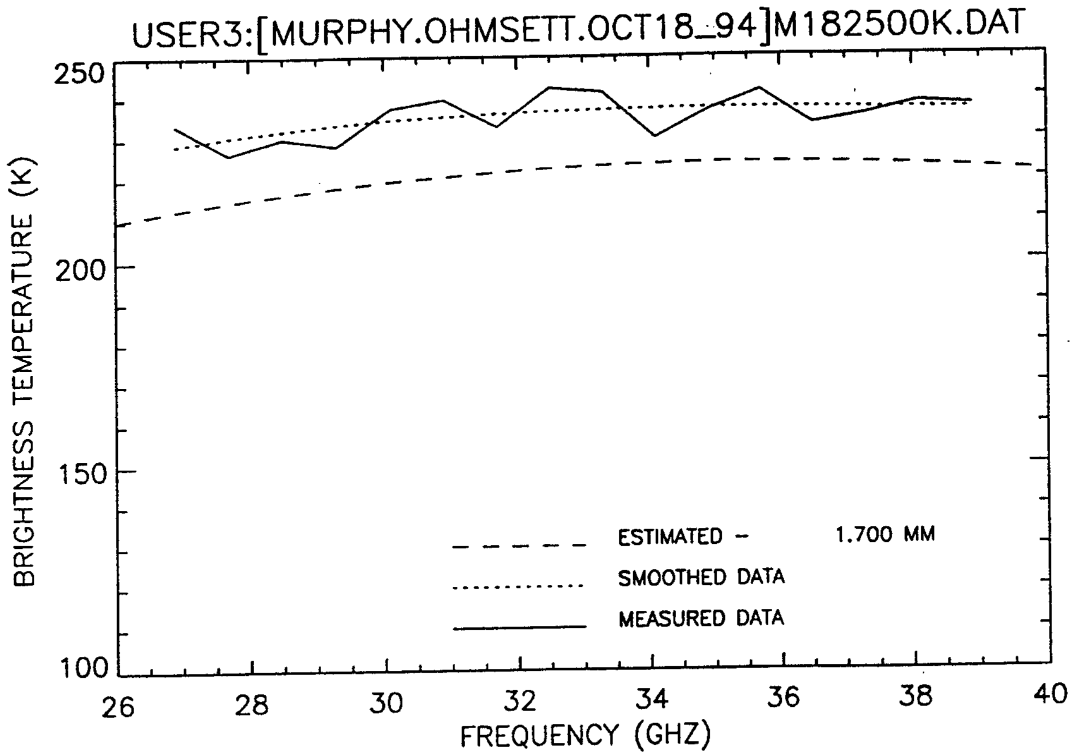

Figure E-48 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 11

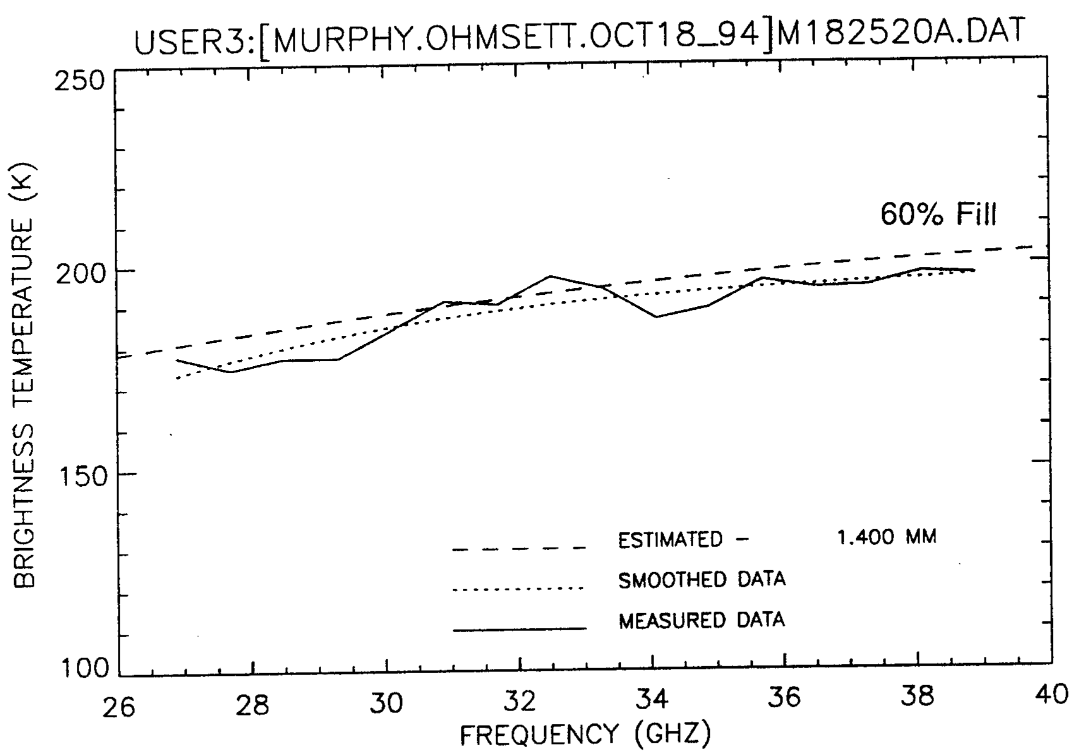

Figure E-49 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 18 October 1994, Pass 1

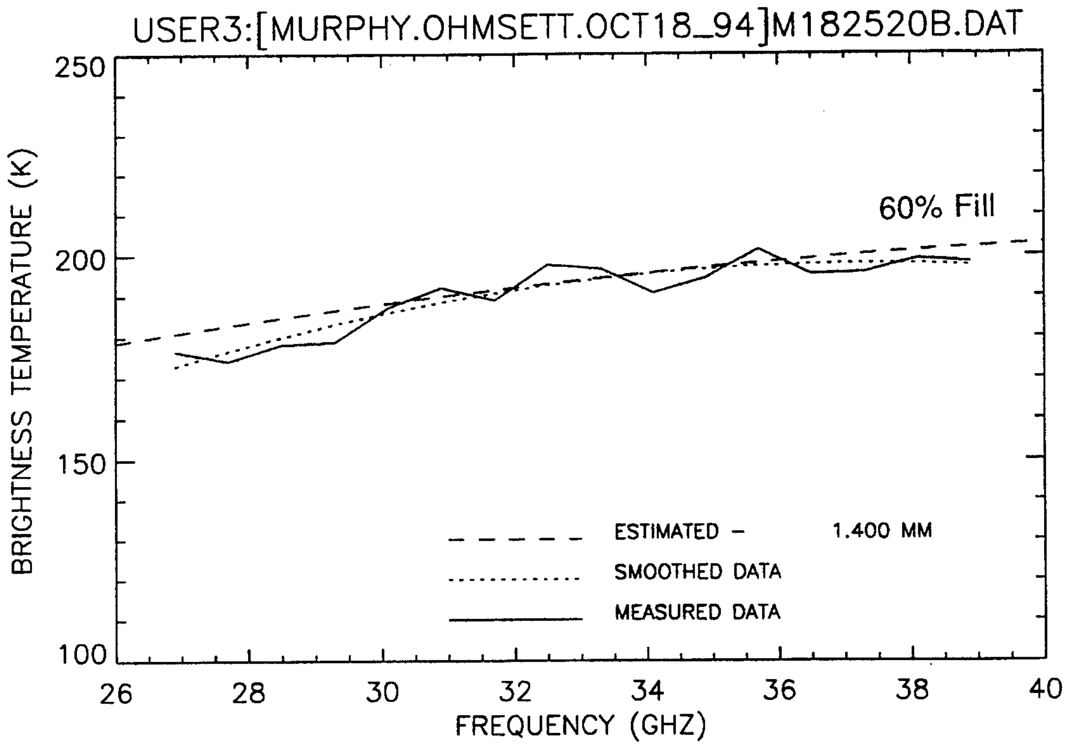

Figure E-50 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 18 October 1994, Pass 2

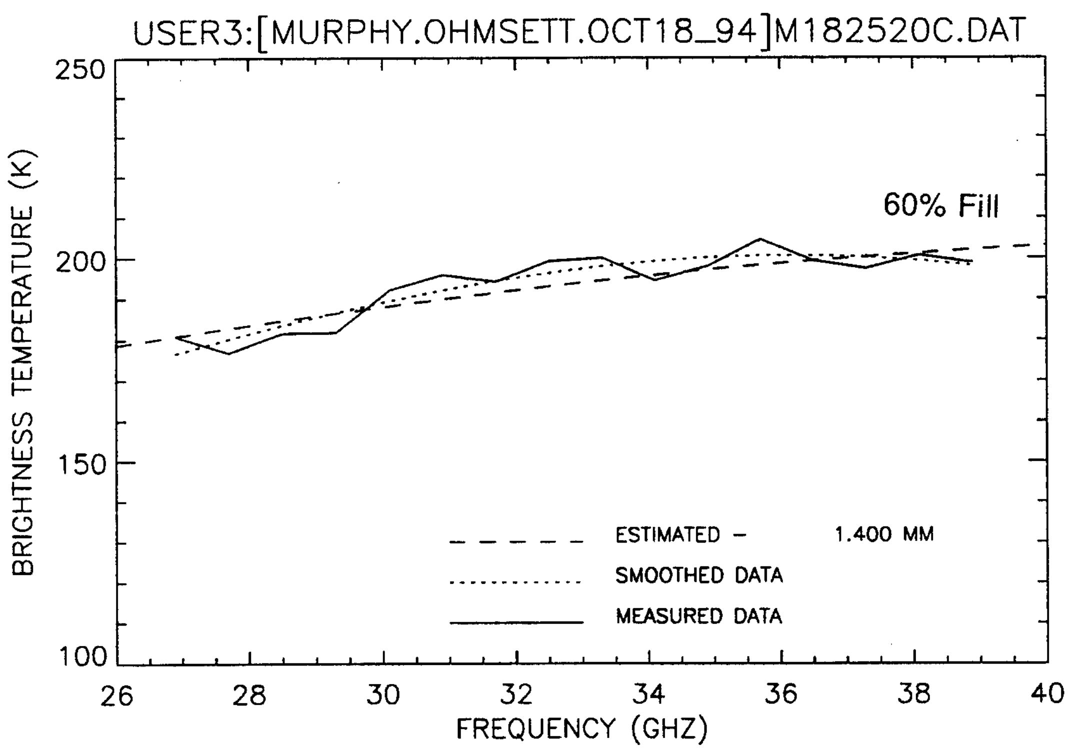

Figure E-51 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 18 October 1994, Pass 3

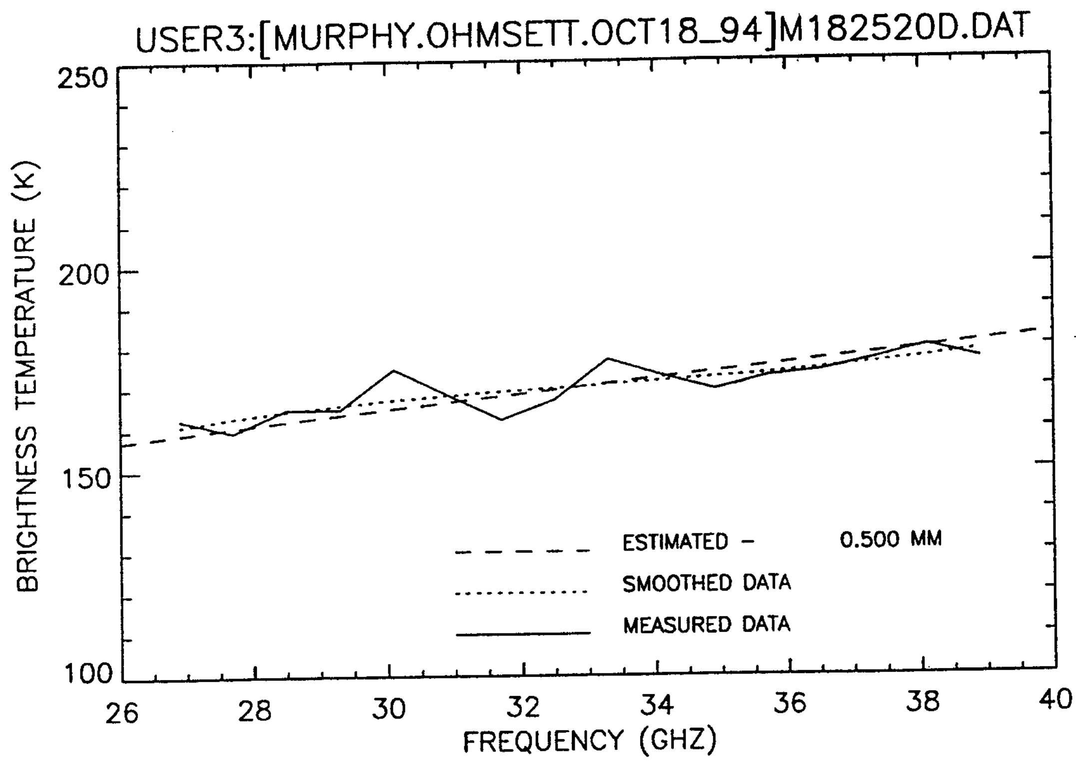

Figure E-52 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 18 October 1994, Pass 4

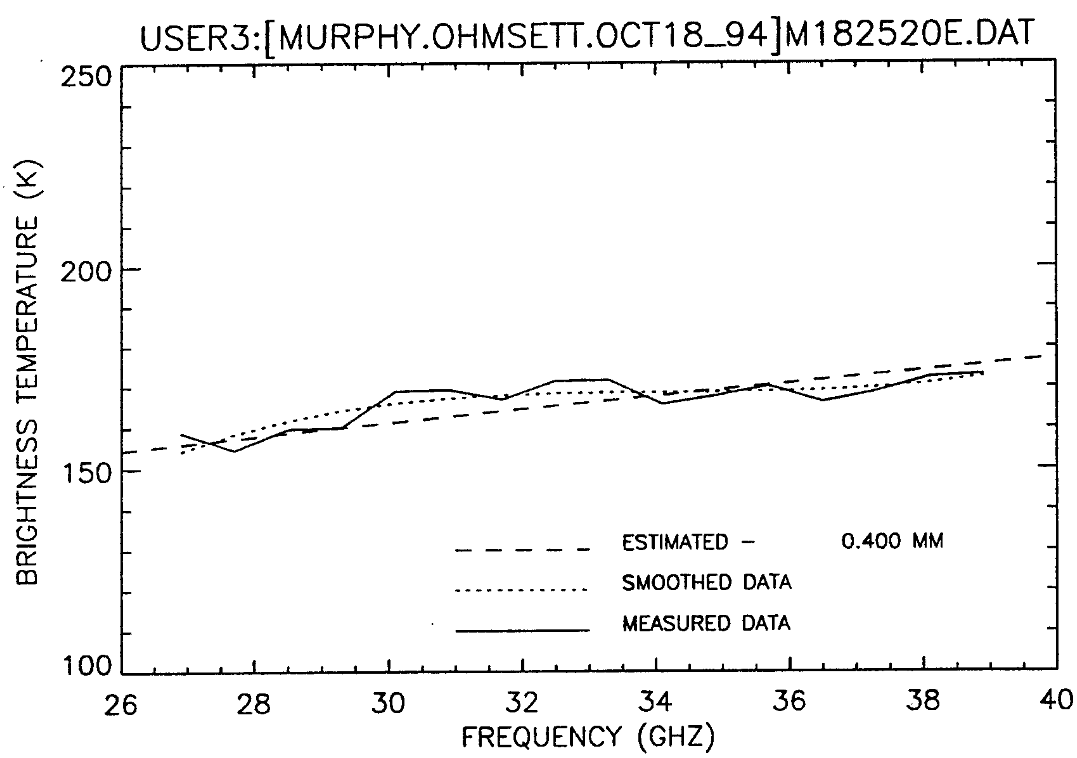

Figure E-53 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 5

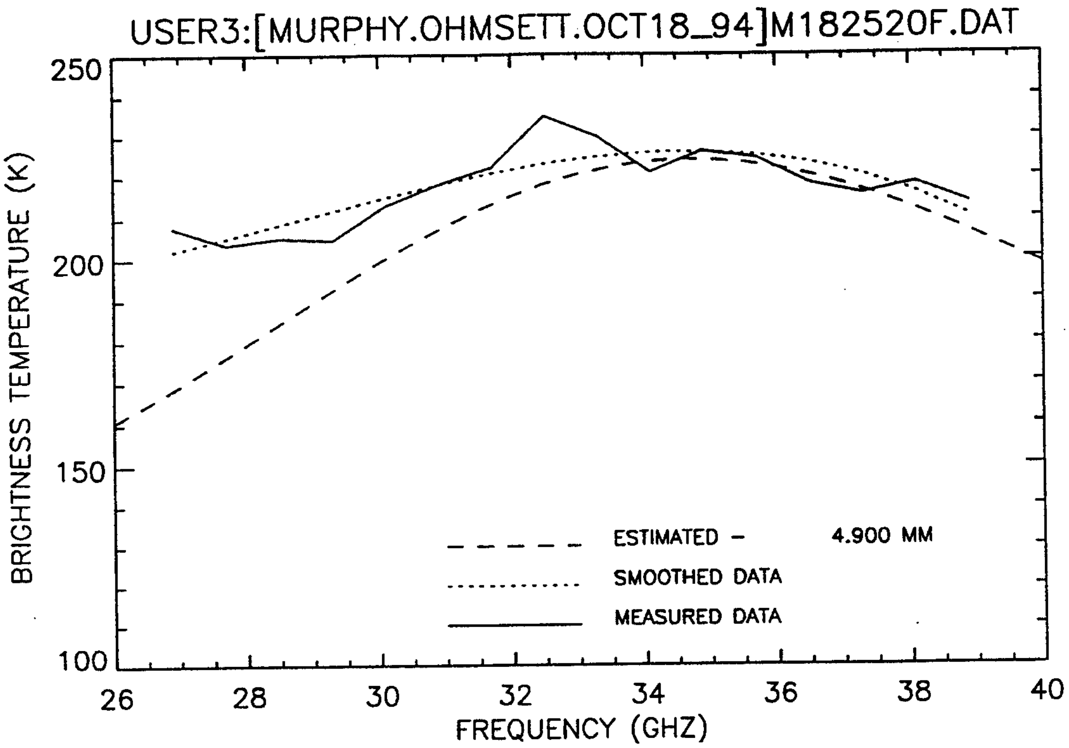

Figure E-54 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 6

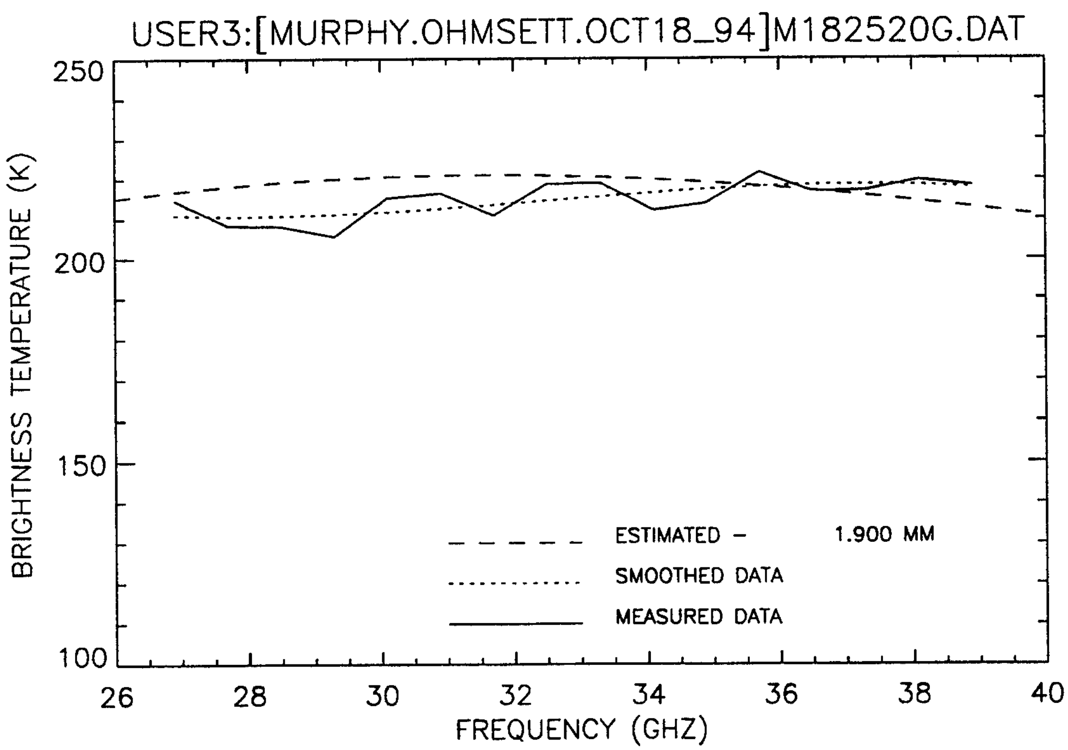

Figure E-55 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 7

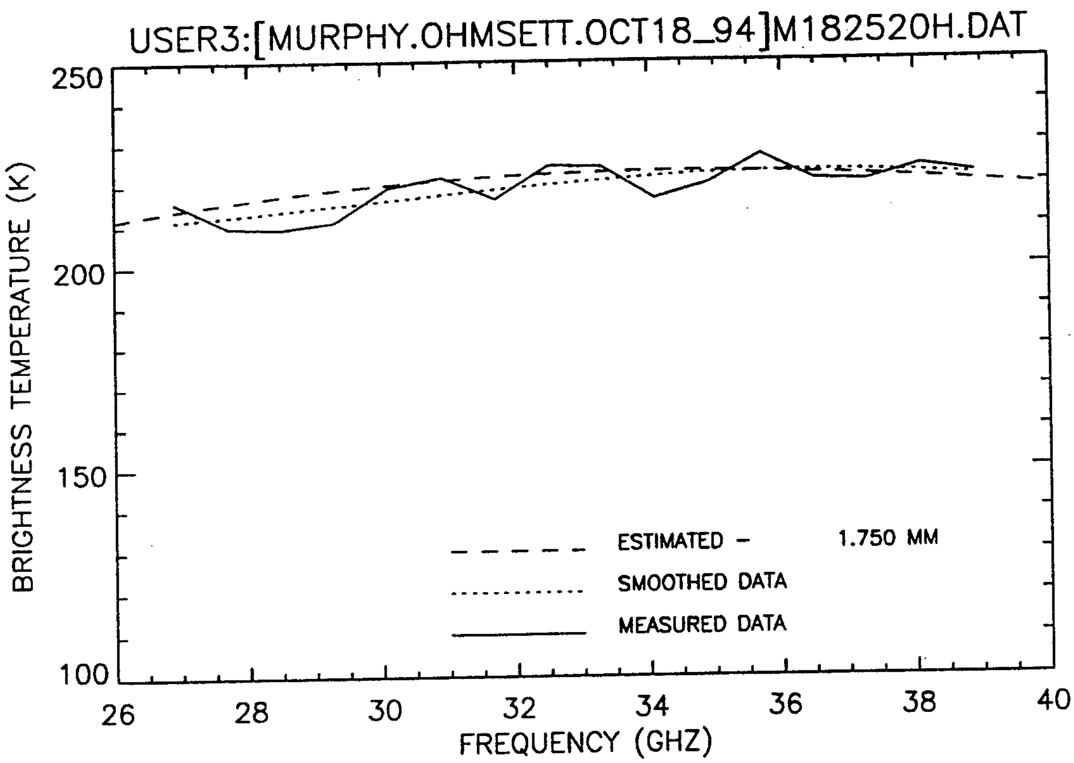

Figure E-56 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 8

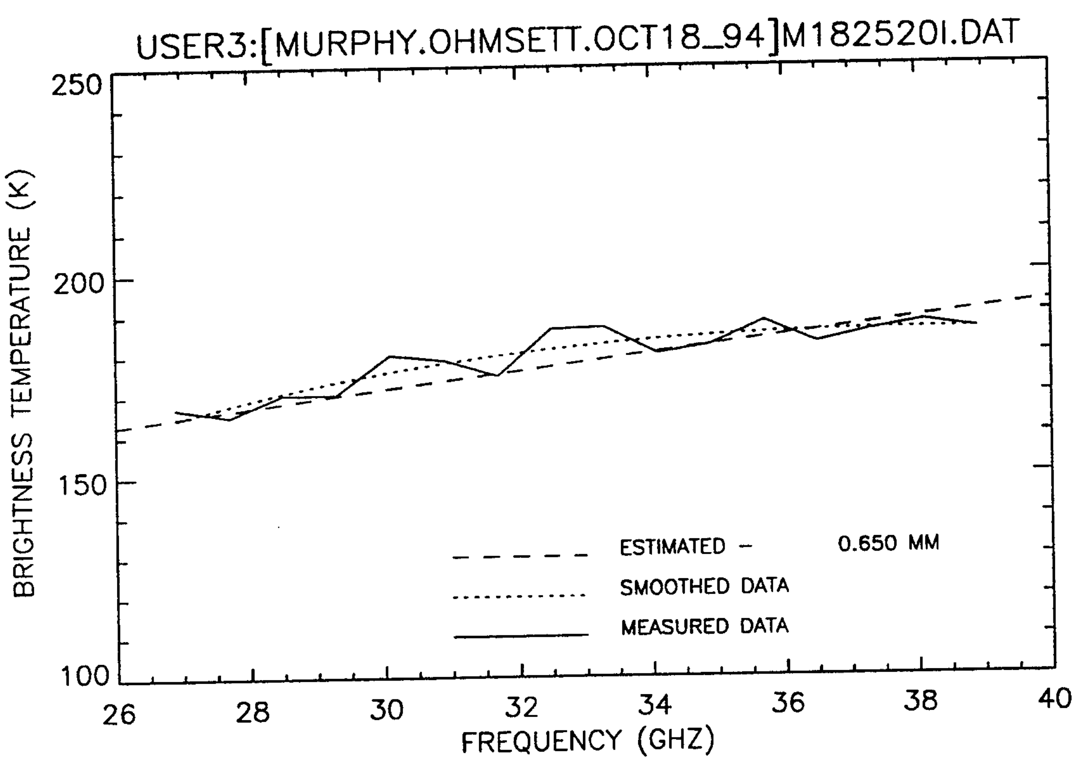

Figure E-57 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 9

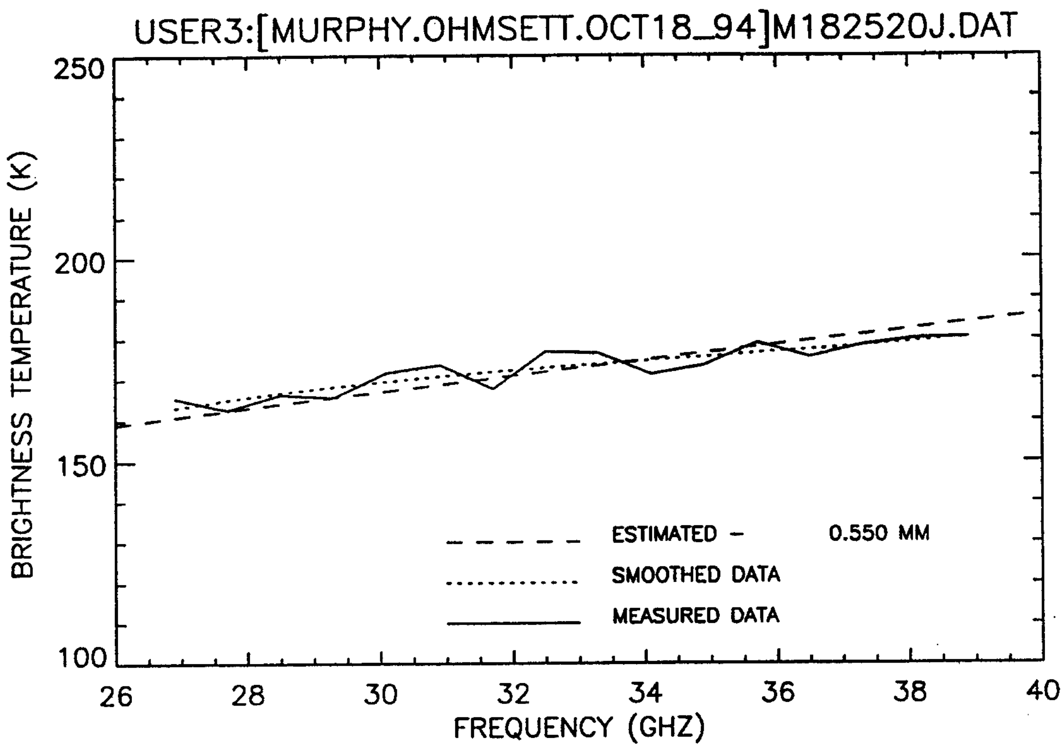

Figure E-58 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 10

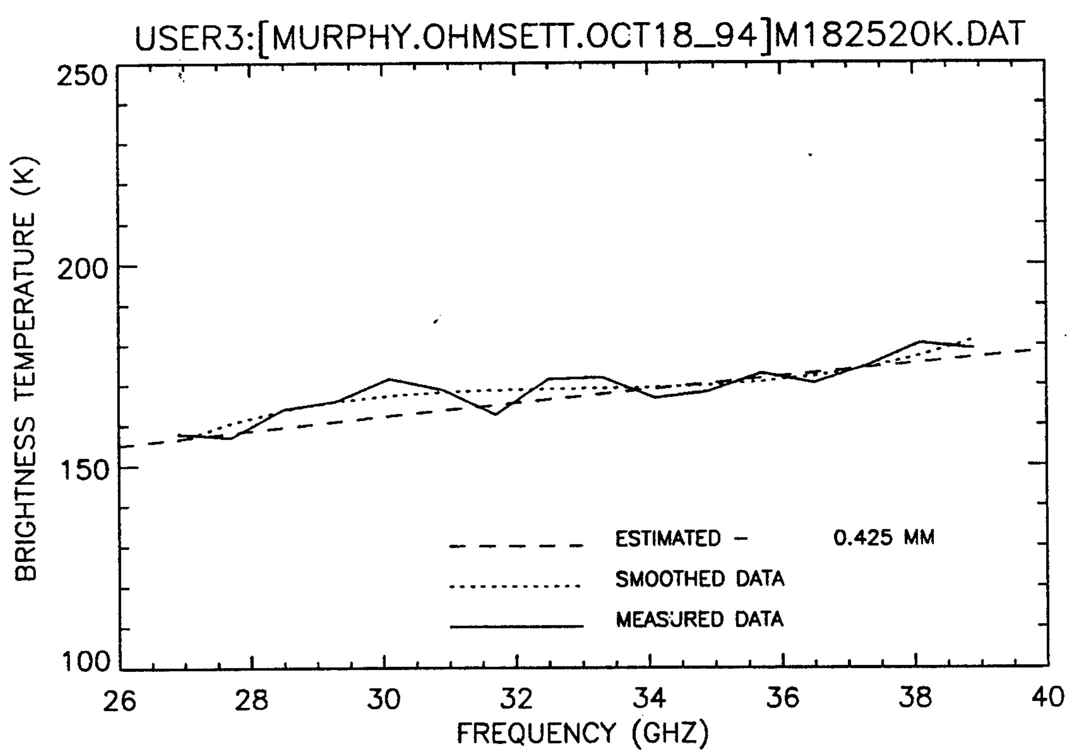

Figure E-59 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 11

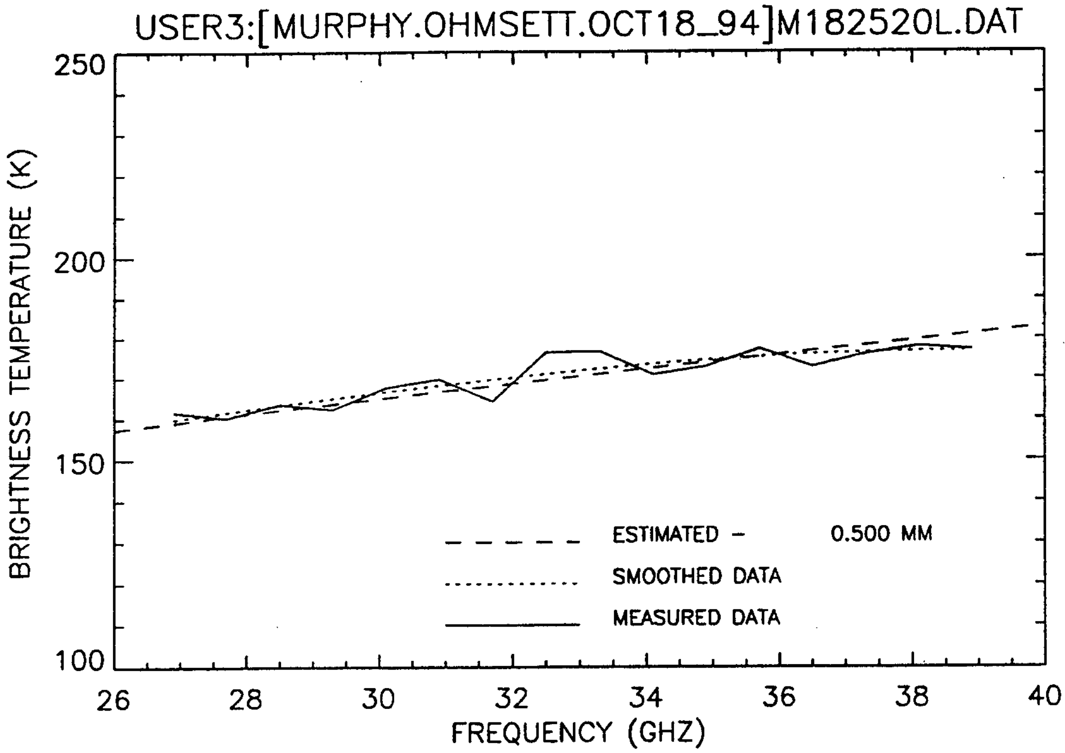

Figure E-60 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 12

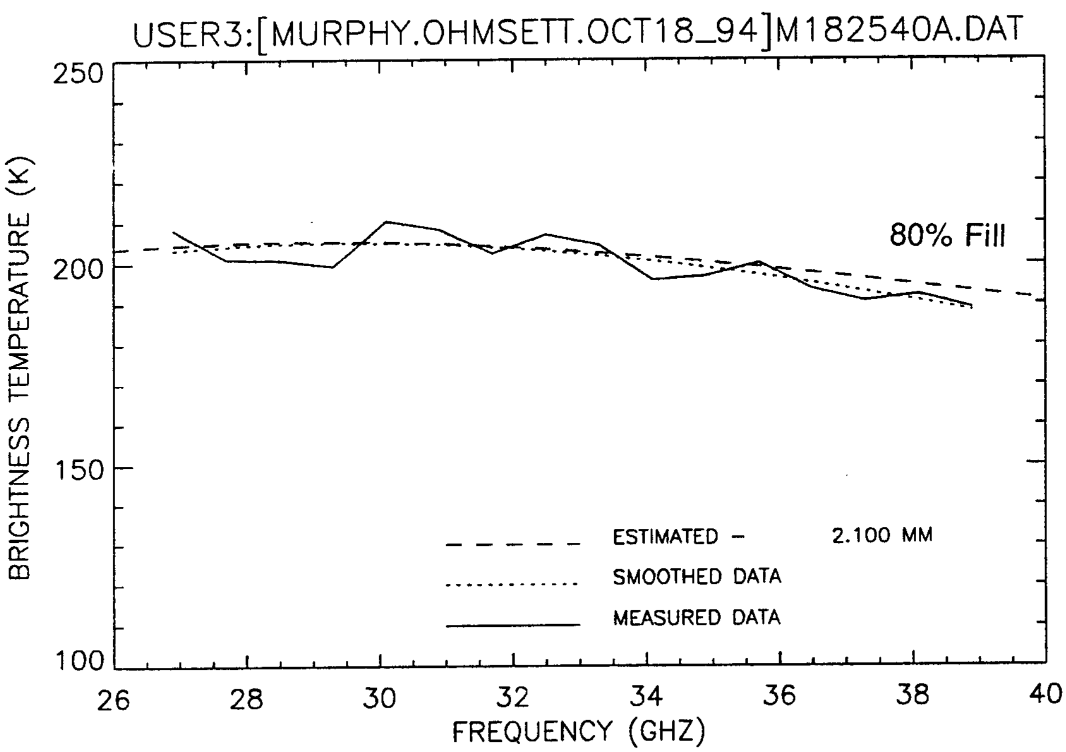

Figure E-61 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 18 October 1994, Pass 1

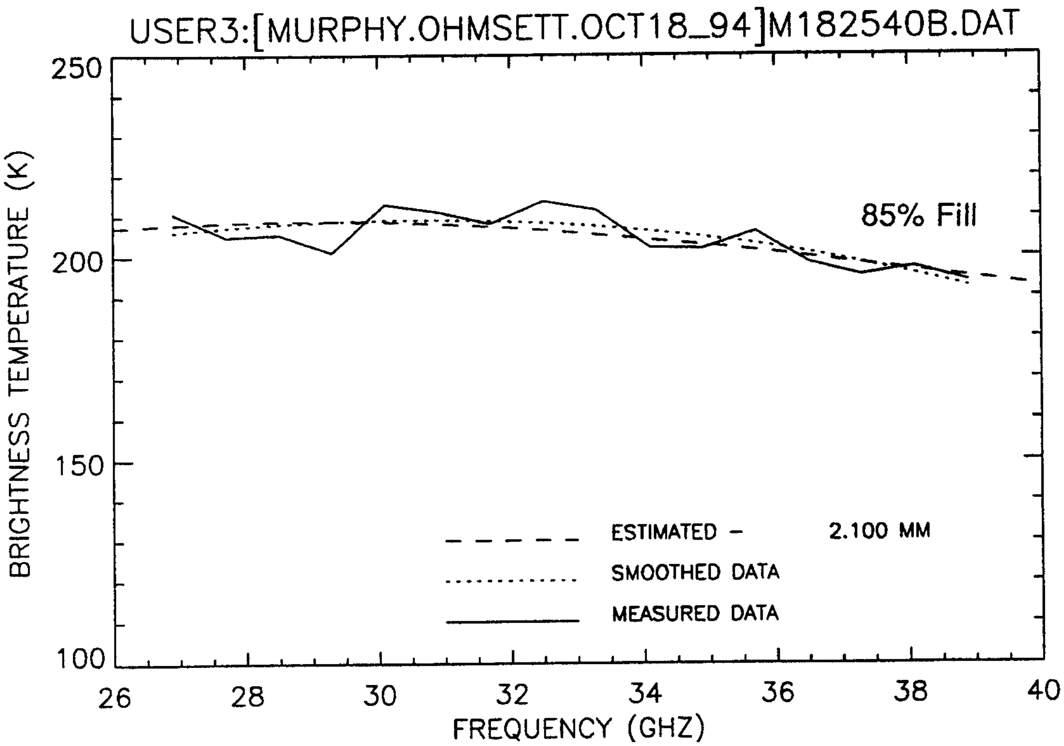

Figure E-62 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 18 October 1994, Pass 2

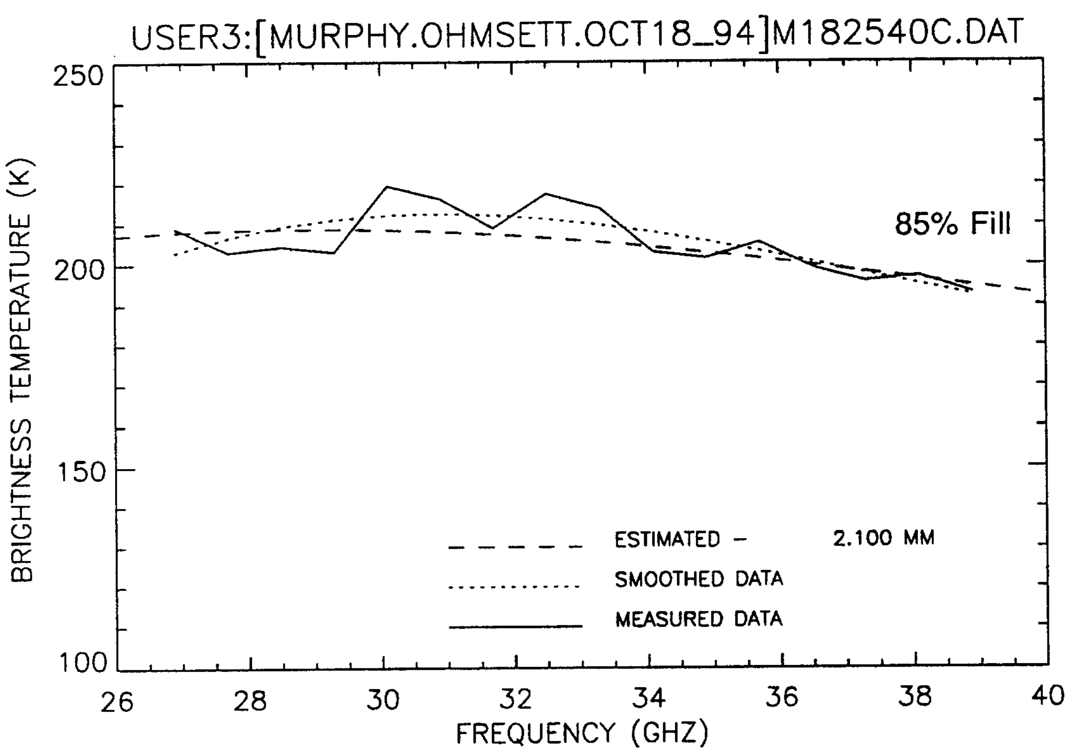

Figure E-63 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 18 October 1994, Pass 3

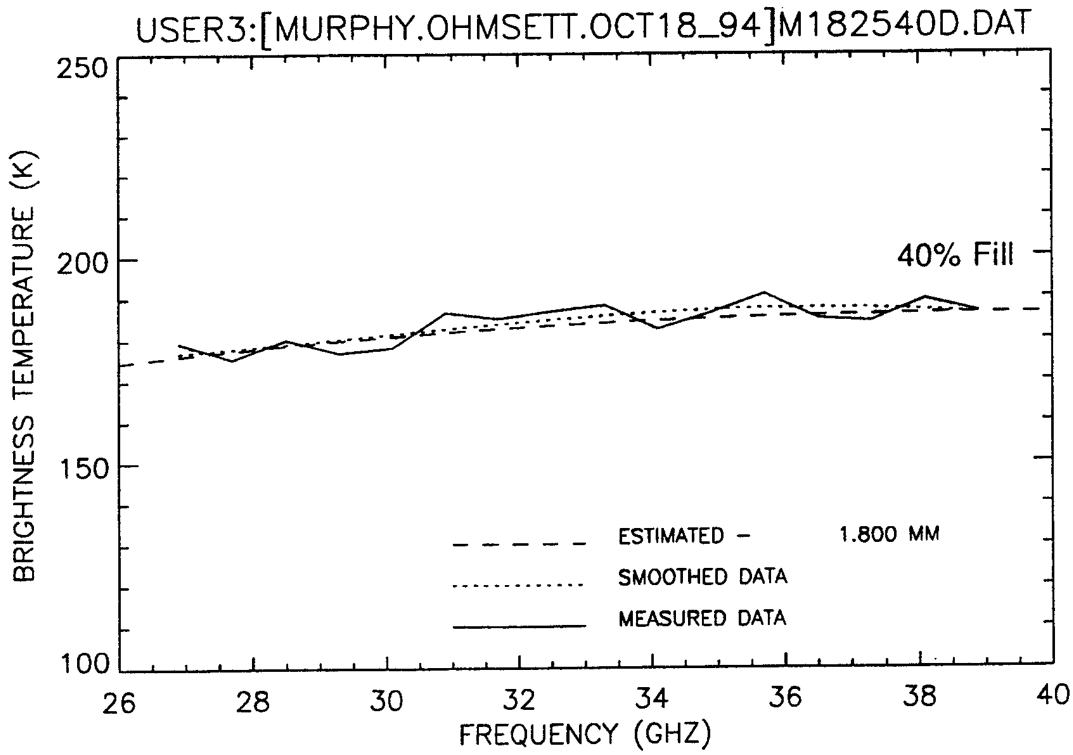

Figure E-64 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 4

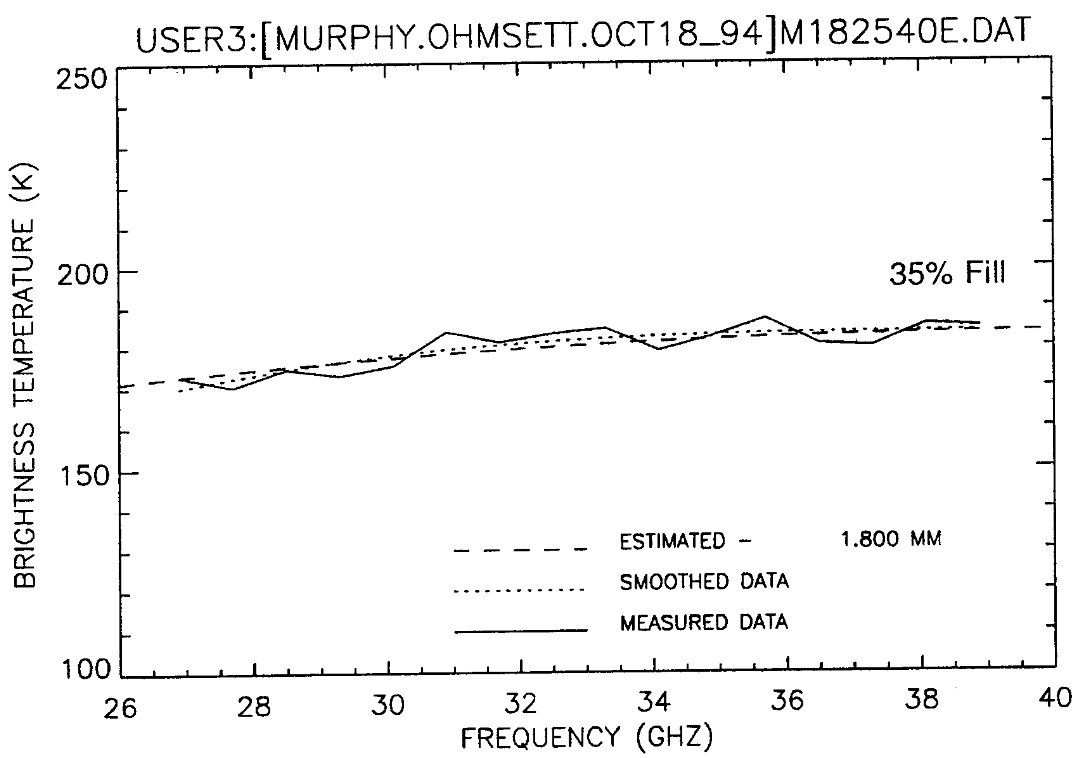

Figure E-65 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 5

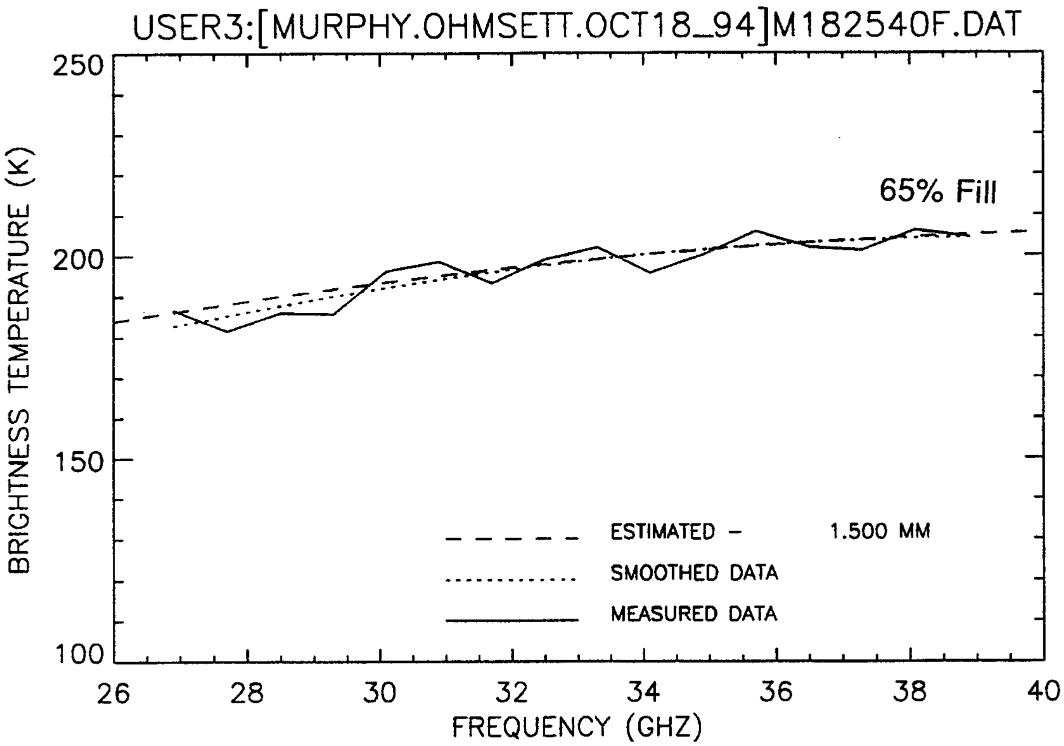

Figure E-66 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 6

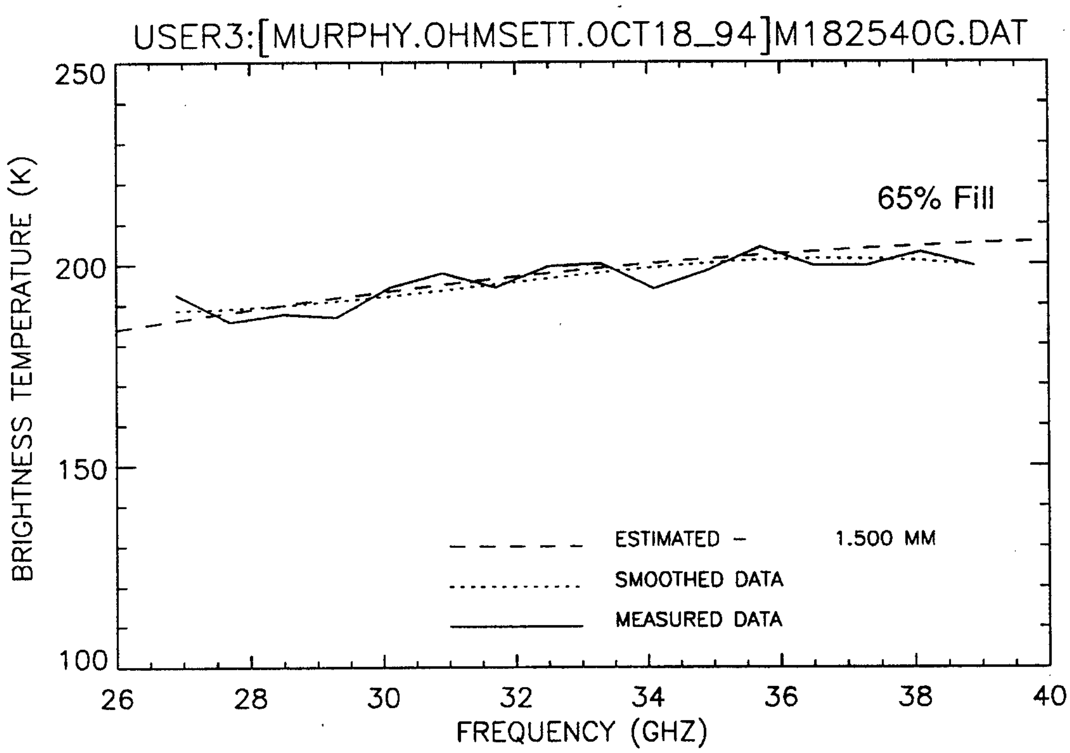

Figure E-67 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 7

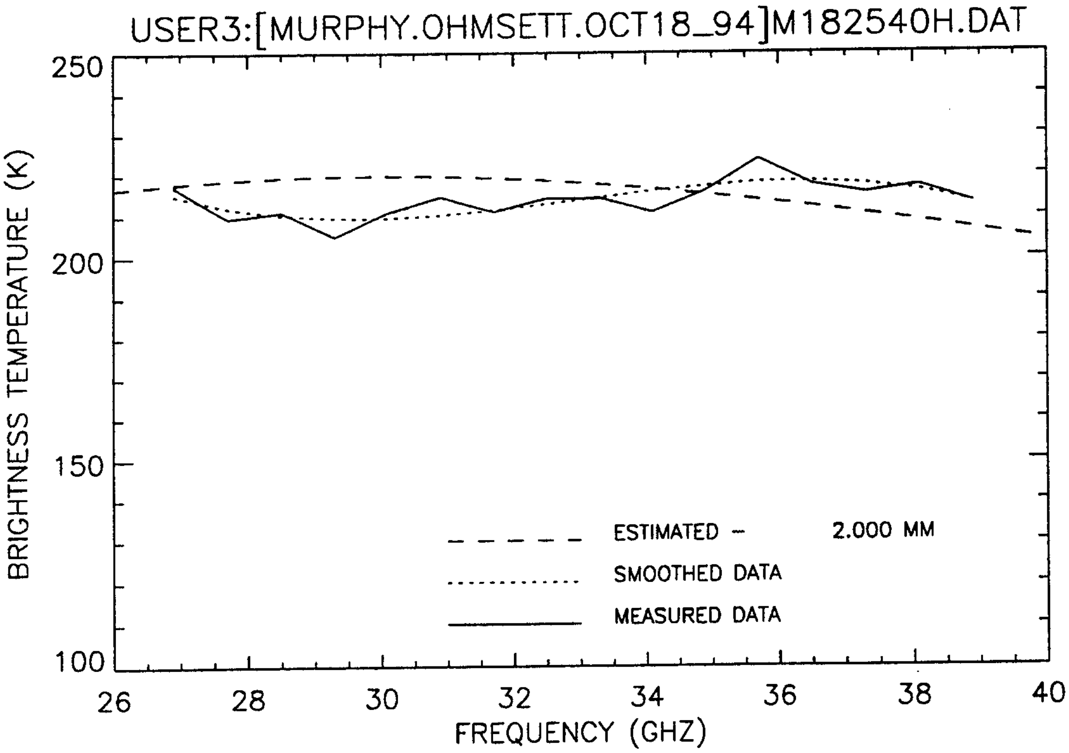

Figure E-68 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 8

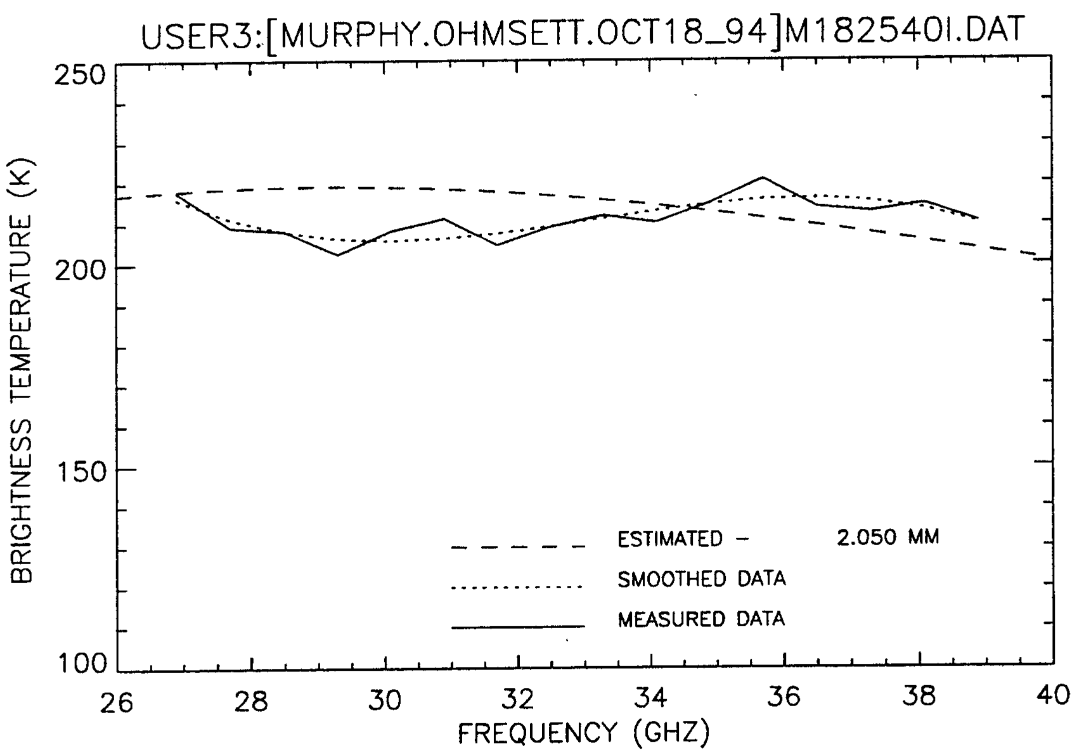

Figure E-69 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 9

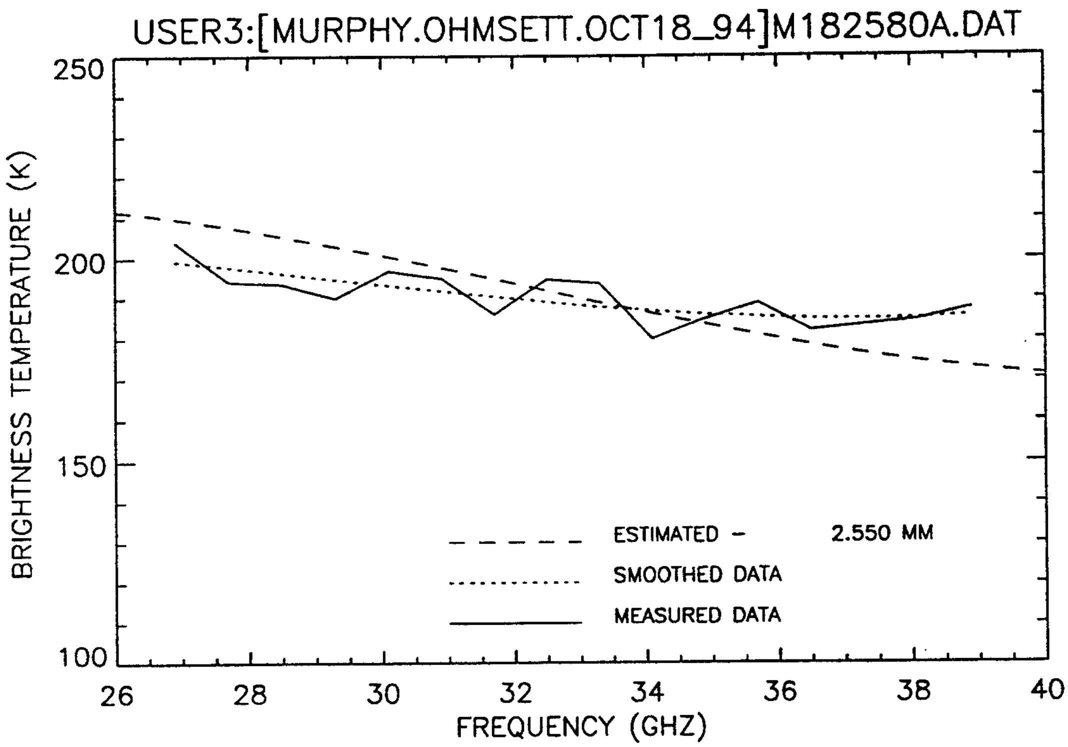

Figure E-70 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, 18 October 1994, Pass 1

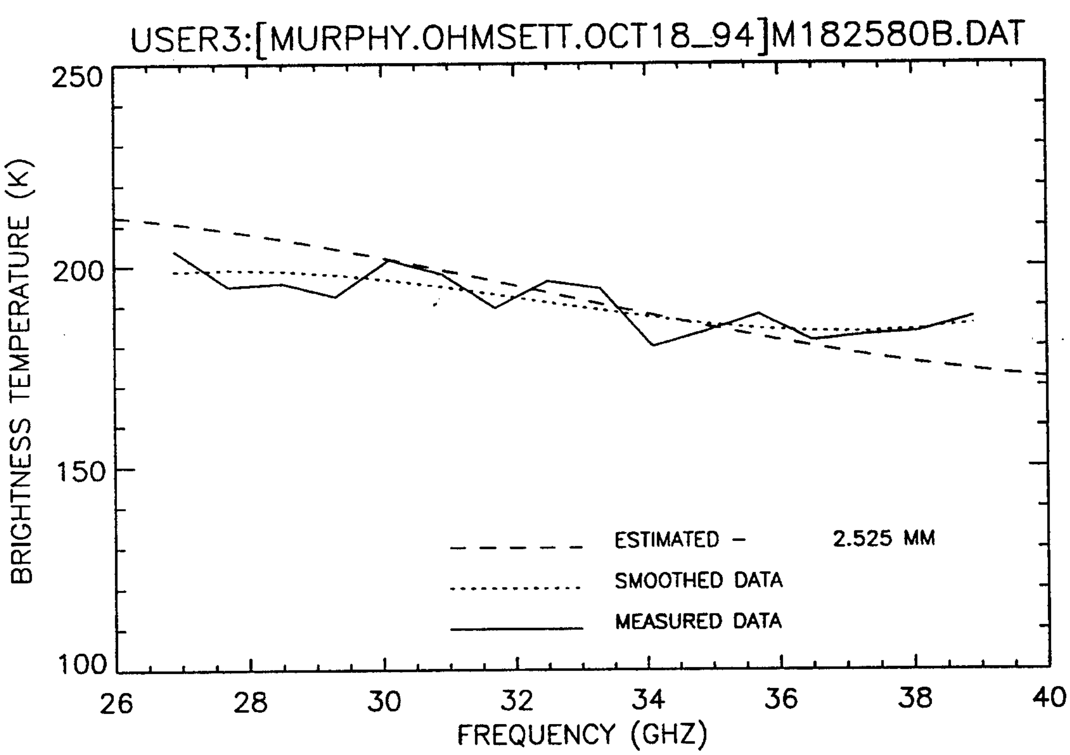

Figure E-71 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, 18 October 1994, Pass 2

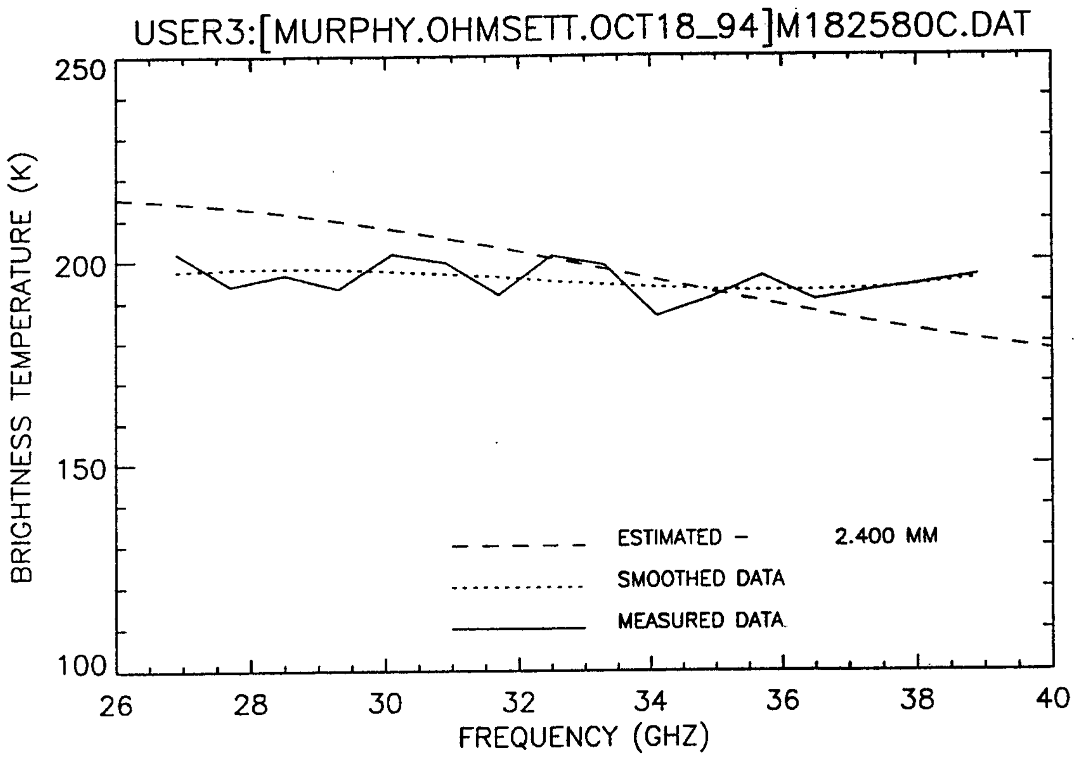

Figure E-72 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, 18 October 1994, Pass 3

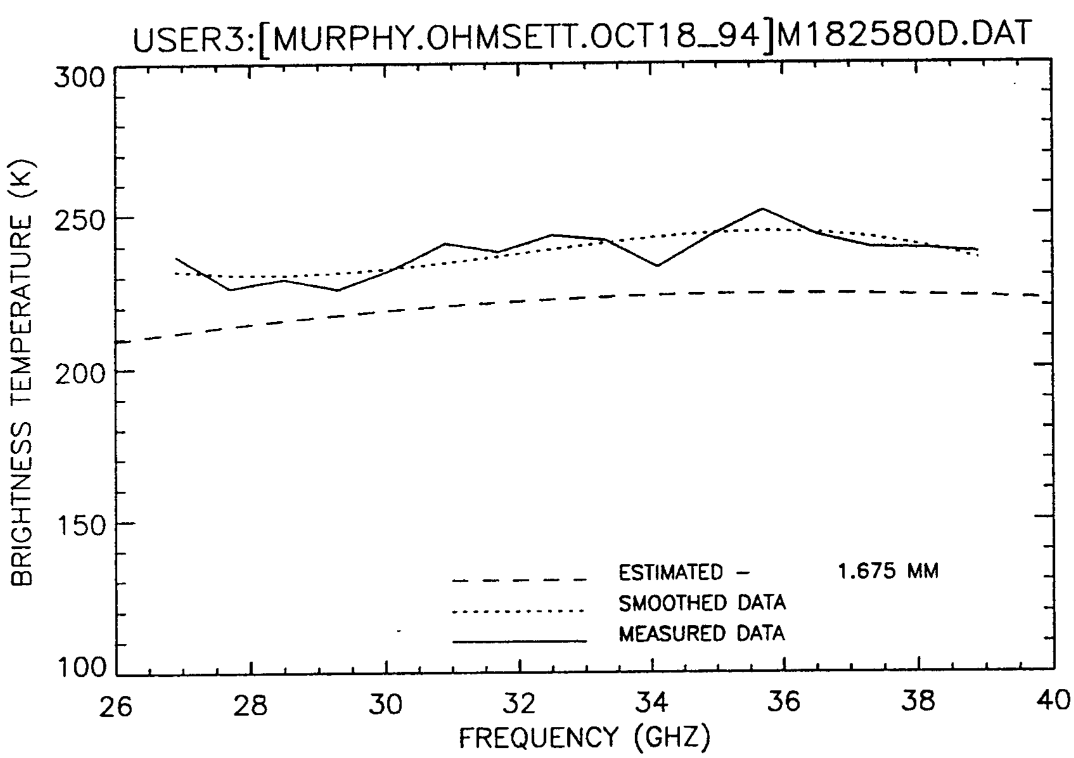

Figure E-73 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 4

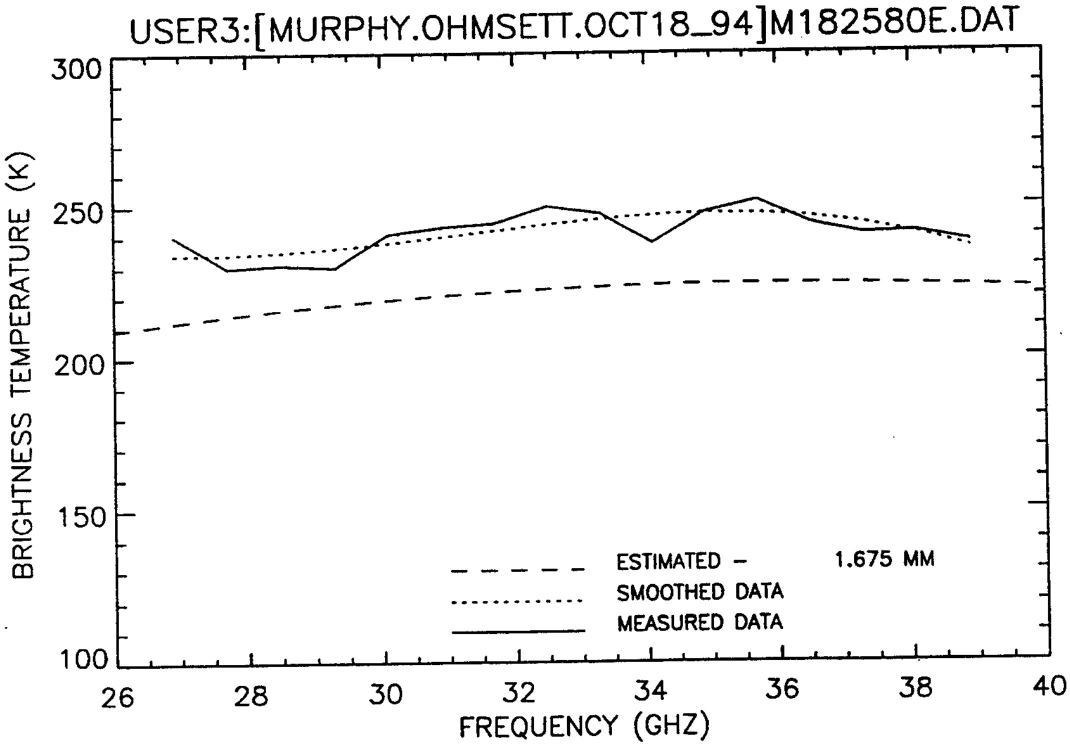

Figure E-74 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 5

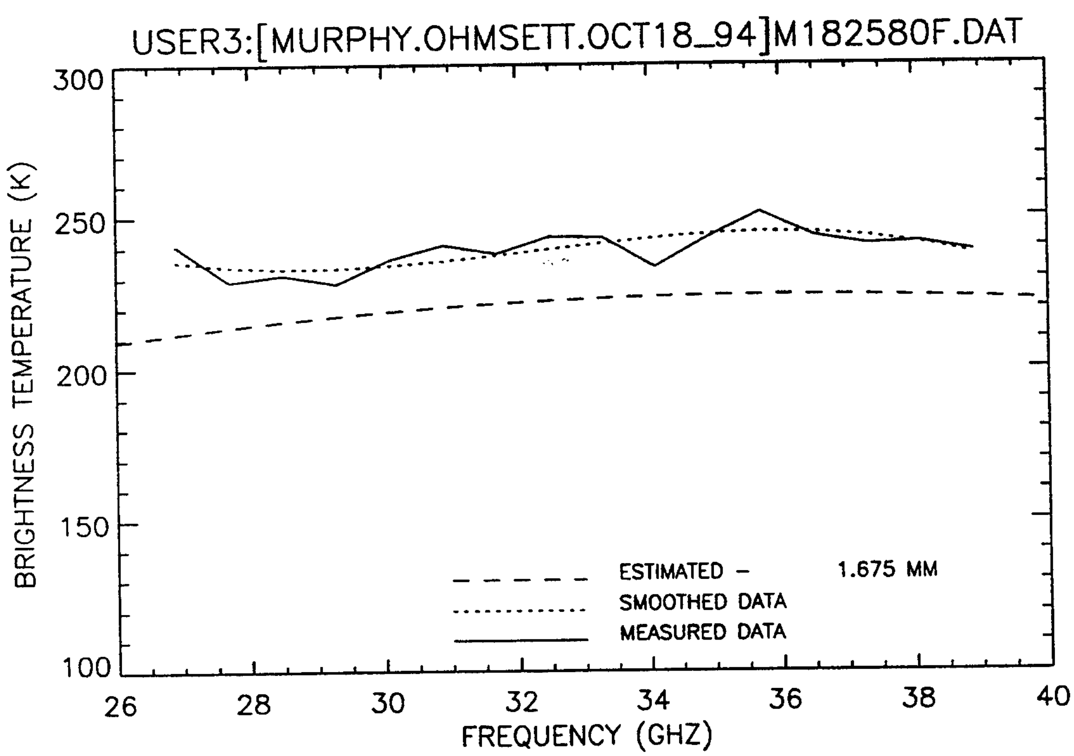

Figure E-75 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 6

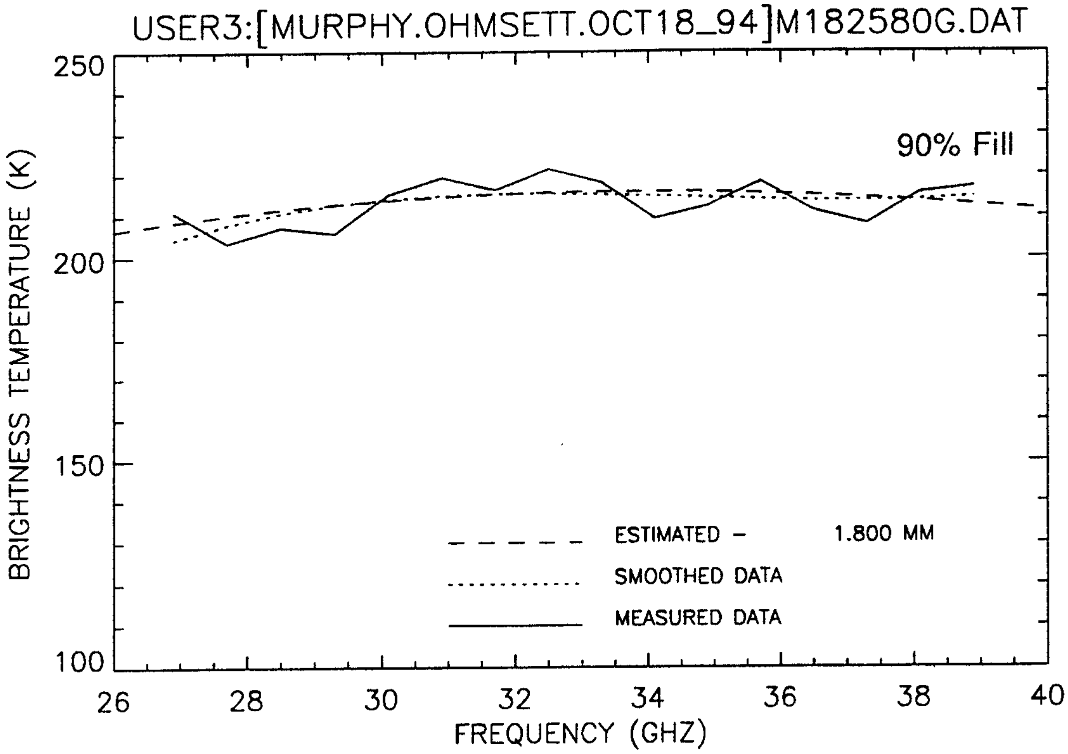

Figure E-76 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 7

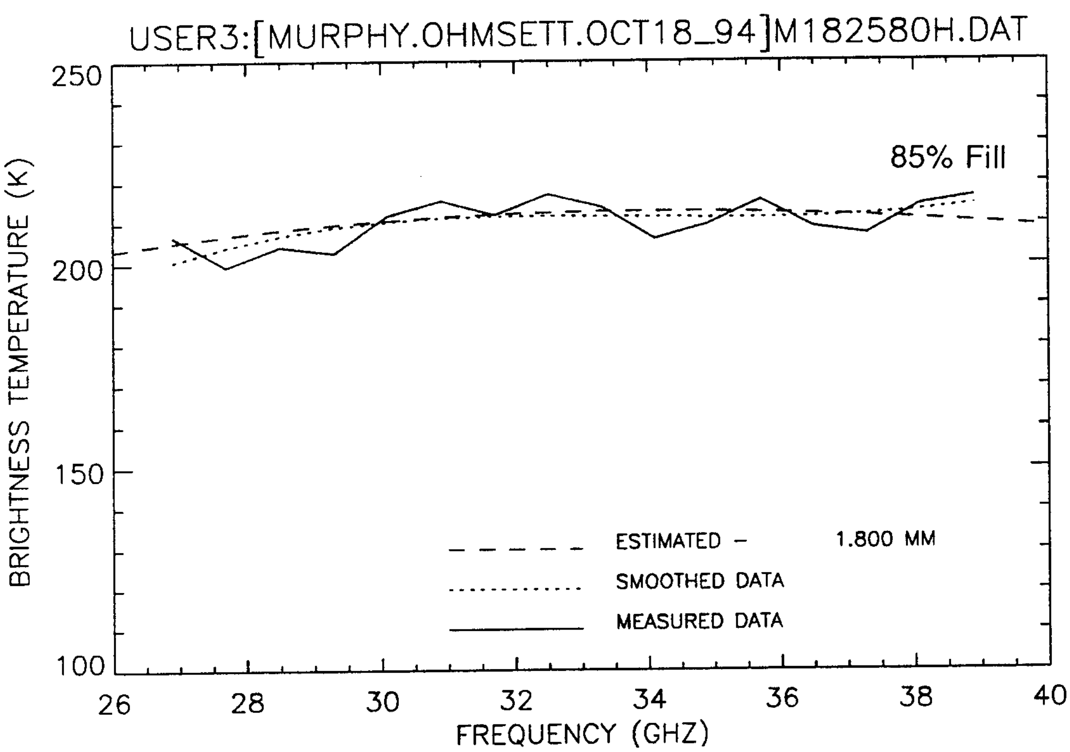

Figure E-77 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, 18 October 1994, Pool Mechanically Stirred to Break-Up Oil, Pass 8

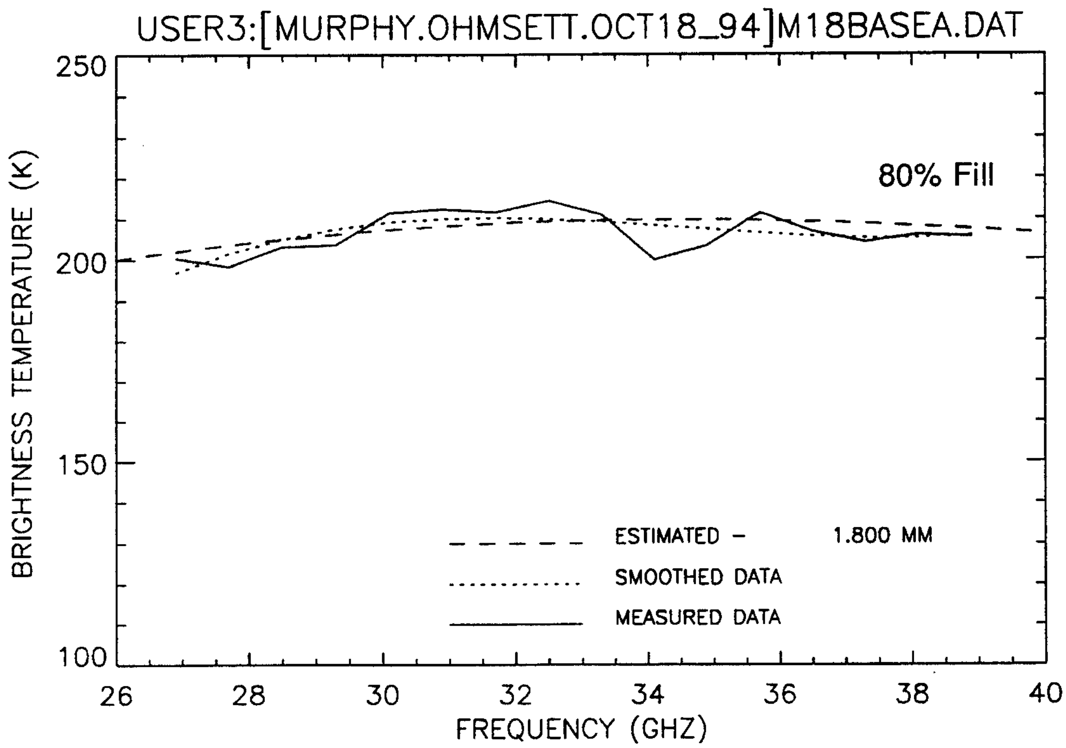

Figure E-78 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, 18 October 1994, Pass 1

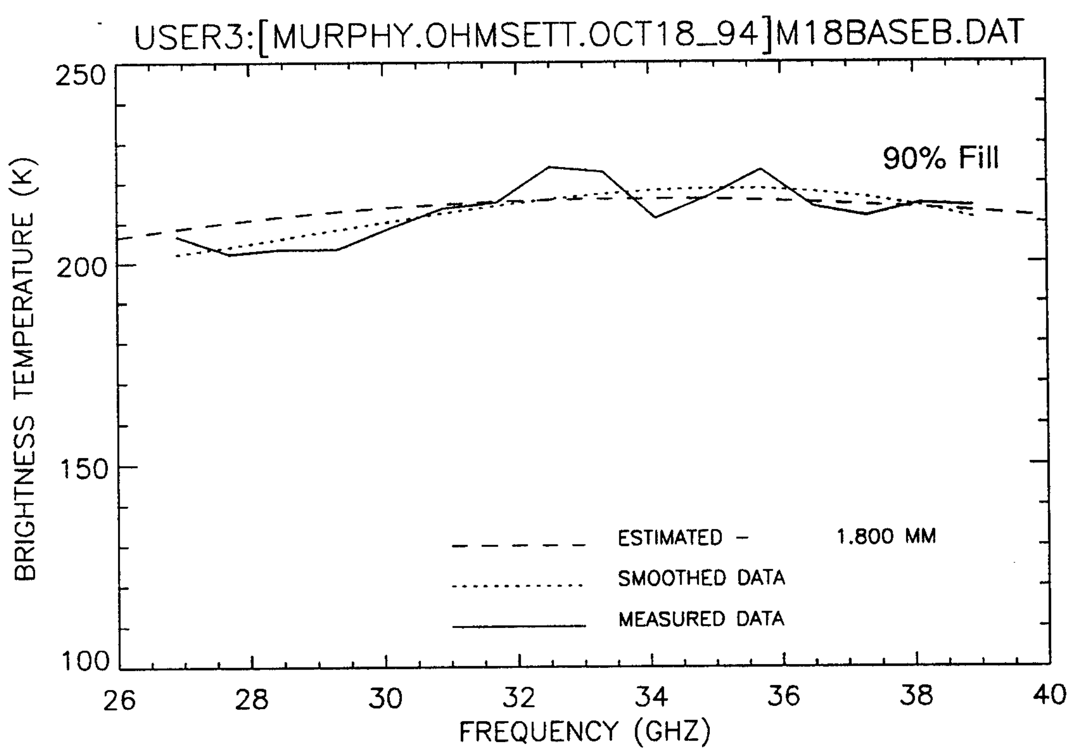

Figure E-79 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, 18 October 1994, Pass 2

The bridge was moved to measure the clean water pool and the wave generator was set to create wave condition 1. Data collection commenced after the waves had reached steady state.

N180000A - This curve was chosen to be the water reference for this set of measurements.

N180000B - This curve is a good-to-excellent match to the algorithm estimate of 0.025 mm. This measurement is only slightly "warmer" than the previous water measurement and is not significantly different from that water measurement. This effect may be due noise fluctuations.

N180000C - This curve is a good match to the algorithm estimate of 0.000 mm.

The following measurements were made in an area of uniform oil coverage over the oil target with 2.5 mm oil at 100% coverage. The antenna footprint was positioned over the area that was previously broken up. The oil had re-formed into what appeared as a uniform film; however, the oil was beginning to look like an emulsion.

N182500A - This curve is a poor match to the algorithm estimate of 1.700 mm. The high overall T^B relative to the 1.7 mm estimate indicates that this might be an emulsion.

N182500B - This curve is a good match to the algorithm estimate of 1.625 mm.

N182500C - This curve is a poor match to the algorithm estimate of 1.700 mm. The high overall T^B relative to the 1.7 mm estimate indicates that this might be an emulsion.

N182500D - This curve is a poor match to the algorithm estimate of 1.700 mm. The high overall T^B relative to the 1.7 mm estimate indicates that this might be an emulsion.

N182500E - This curve is a fair match to the algorithm estimate of 1.450 mm.

The main bridge was moved to the 2.5 mm 10% coverage oil target. An area was chosen to obtain maximum antenna beam fill with the oil in this target. The beam fill was estimated to be 60%. The surface of the oil did not appear to show any effects of mixing with water.

N182510A - This curve is a fair match to the algorithm estimate of 0.450 mm. The slope of the measured line seems steeper than theoretical prediction; however, the mean T^B seems to be in the correct range. The steepness of the slope may be due to a partial beam fill of thicker oil; however, based on the up-sloping characteristic, the oil thickness would not be greater than approximately 1.2 mm. Attempts to match this curve with partial beam fill of 40 -80% using single oil thicknesses from 0.5 mm to 1.5 mm proved unsuccessful.

N182510B - This curve is a fair match to the algorithm estimate of 0.425 mm. The slope of the measured line seems steeper than theoretical prediction; however, the mean T^B seems to be in the correct range. The steepness of the slope may be due to a partial beam fill of thicker oil; however, based on the up-sloping characteristic, the oil thickness would not be greater than approximately 1.2 mm. Attempts to match this curve with partial beam fill of 40 -80% using single oil thicknesses from 0.5 mm to 1.5 mm proved unsuccessful.

N182510C - This curve is a fair match to the algorithm estimate of 0.525 mm. The slope of the measured line seems steeper than theoretical prediction; however, the mean T^B seems to be in the correct range. The steepness of the slope may be due to a partial beam fill of thicker oil; however, based on the up-sloping characteristic, the oil thickness would not be greater than approximately 1.2 mm. Attempts to match this curve with partial beam fill of 40 -80% using single oil thicknesses from 0.5 mm to 1.5 mm proved unsuccessful.

The main bridge was positioned over the 2.5 mm, 20% coverage pool. These measurements were made from the south end of the pool, with an oil target antenna beam fill of approximately 40%.

N182520A - This curve is a poor match to the algorithm estimate of 0.700 mm. The measured data set seems noisy. The result is inconclusive.

N182520B - This curve is a good match to the algorithm estimate of 0.500 mm.

N182520C - This curve is a good match to the algorithm estimate of 0.400 mm.

The main bridge was positioned over the 2.5 mm, 40% coverage pool. These measurements were made from the center of the of the oil target, with an oil target antenna beam fill of approximately 70%.

N182540A - This curve is a good match to the algorithm estimate of 1.750 mm.

N182540B - This curve is a poor match to the algorithm estimate of 2.075 mm. The shape seems to match well, but the overall T^B is too low. The result is inconclusive.

N182540C - This curve is a poor-to-fair match to the algorithm estimate of 1.325 mm. The slope for this curve seems to be too flat compared to the theoretical estimate. Using a partial beam fill of 90% with a 1.7 mm thickness (plotted) produced an excellent match.

The main bridge was positioned over the 2.5 mm, 80% coverage pool. These measurements were made from an area that was not previously stirred or otherwise broken up during earlier measurements. The beam fill is estimated to be 95%.

N182580A - This curve is a poor match to the algorithm estimate of 2.225 mm. The shape of the curve matches a 1.9 mm estimate, but the overall T^B is too low. Using a partial beam fill of 80% with the 1.9 mm thickness (plotted) produced an excellent match.

N182580B - This curve is a poor-to-fair match to the algorithm estimate of 2.150 mm. The shape of the curve matches a 1.9 mm estimate but the overall T^B is too low. Using a partial beam fill of 85% with the 1.9 mm thickness (plotted) produced an excellent match.

N182580C - This curve is a poor match to the algorithm estimate of 2.200 mm. The shape seems to be a good match to an estimate of 1.9 mm, but the overall T^B is too low. Using a partial beam fill of 80% with the 1.9 mm thickness (plotted) produced an excellent match.

The main bridge was moved south to an area where the oil had been broken up and had begun to re-form. The antenna beam fill is estimated to be 95%.

N182580D - This curve is a poor match to the algorithm estimate of 0.875 mm. .
Using a partial beam fill of 60% with a 1.9 mm thickness (plotted) produced an excellent match.

N182580E - This curve is a poor match to the algorithm estimate of 0.875 mm. .
Using a partial beam fill of 60% with the 1.9 mm thickness (plotted) produced an excellent match.

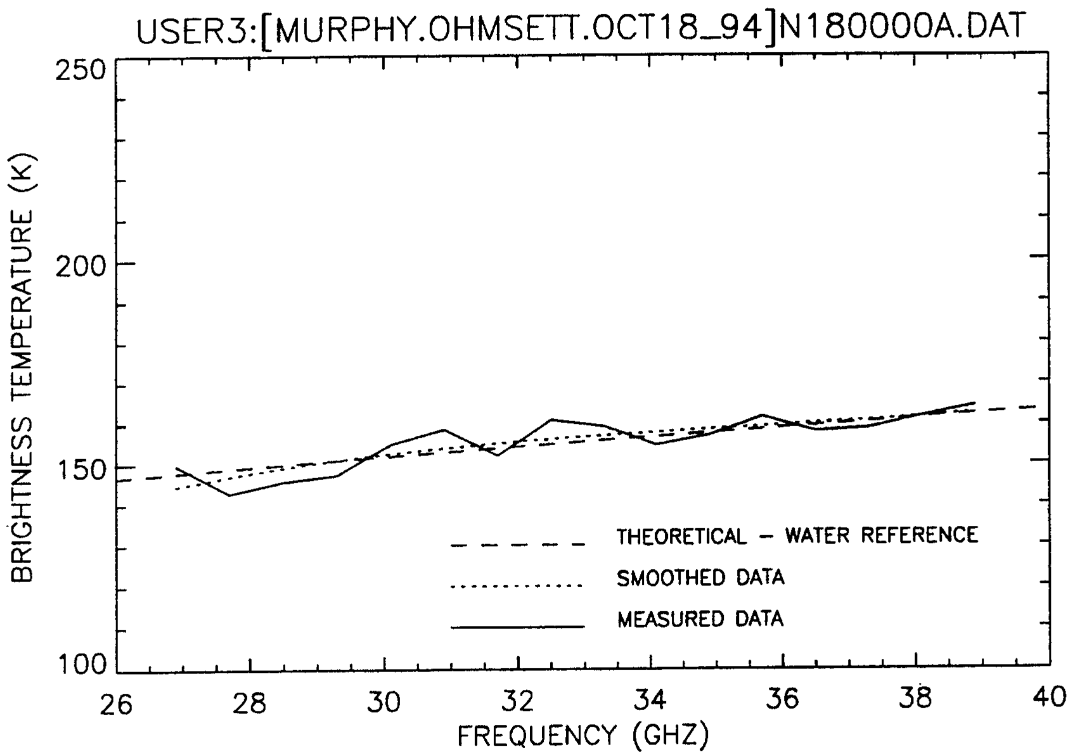

Figure E-80 T^B Versus Frequency Plot for Background Water, Wave Condition 1, 18 October 1994, Pass 1

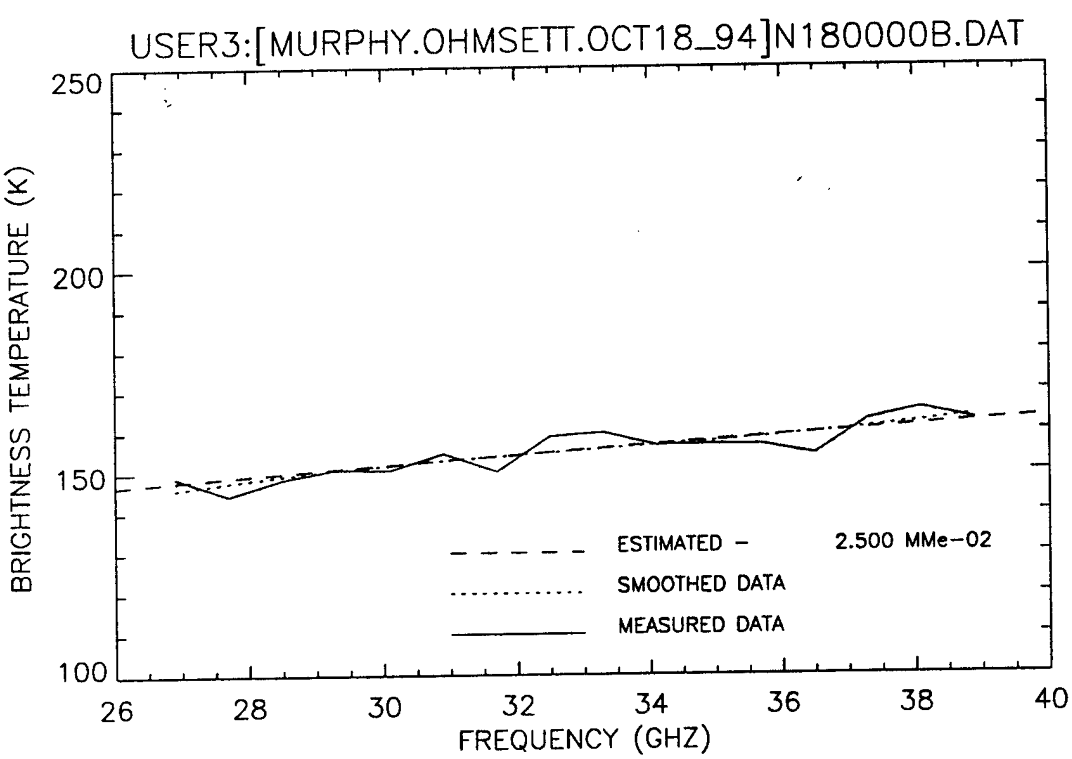

Figure E-81 T^B Versus Frequency Plot for Background Water, Wave Condition 1, 18 October 1994, Pass 2

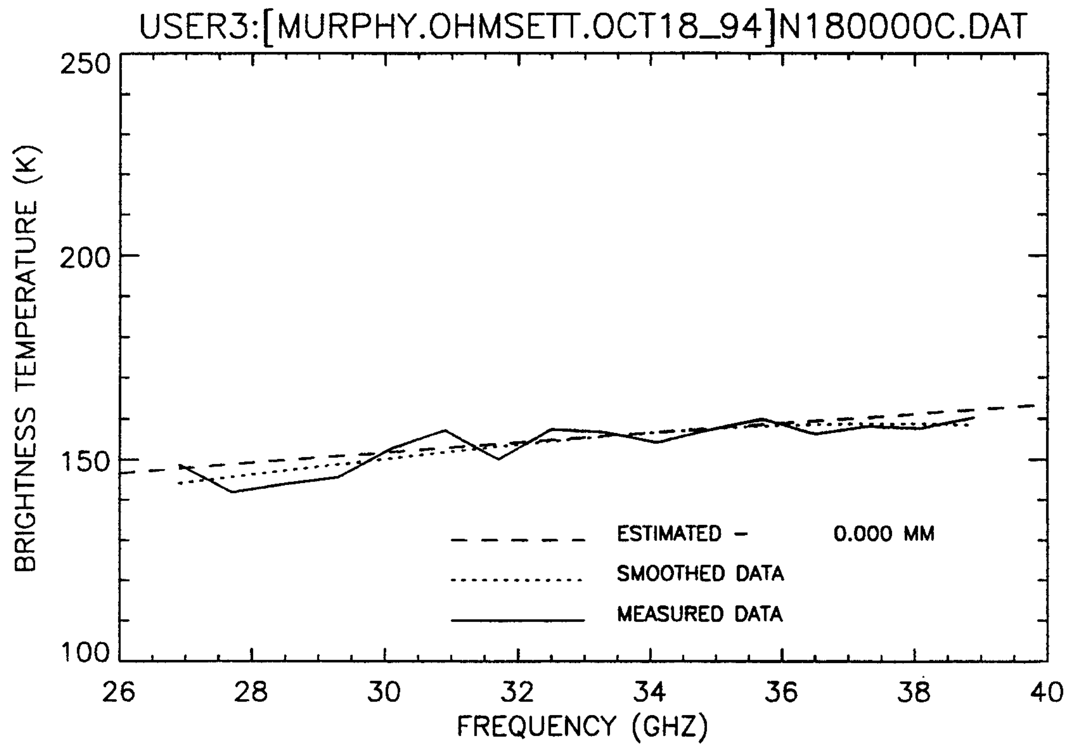

Figure E-82 T^B Versus Frequency Plot for Background Water, Wave Condition 1, 18 October 1994, Pass 3

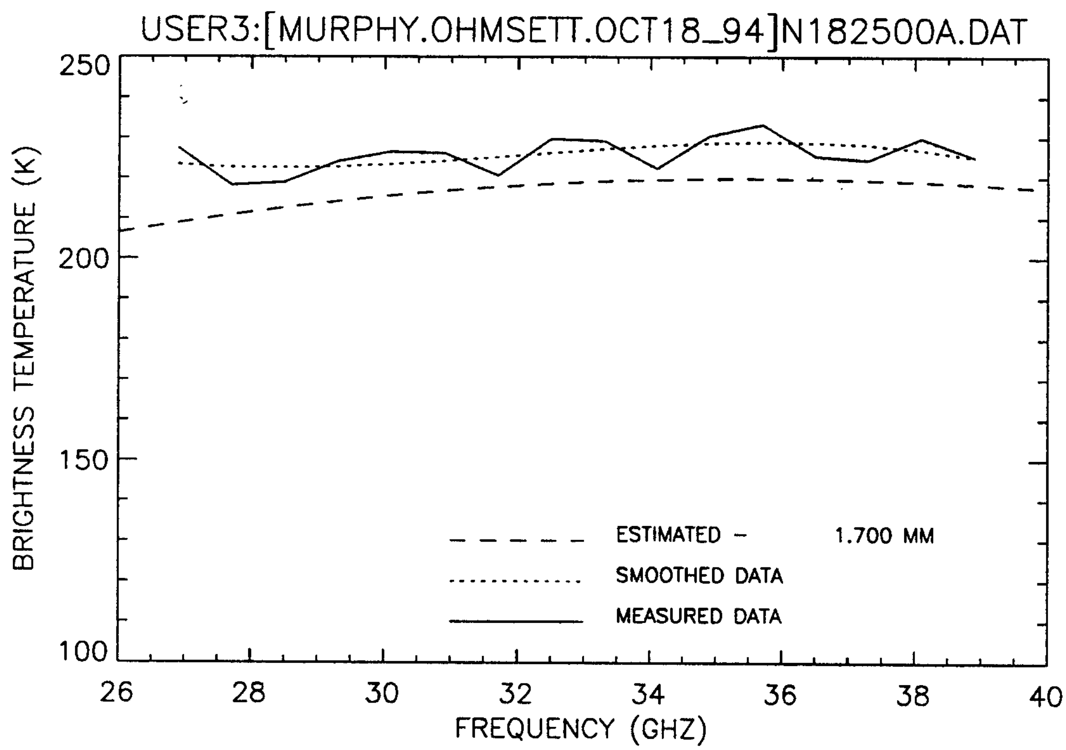

Figure E-83 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 1

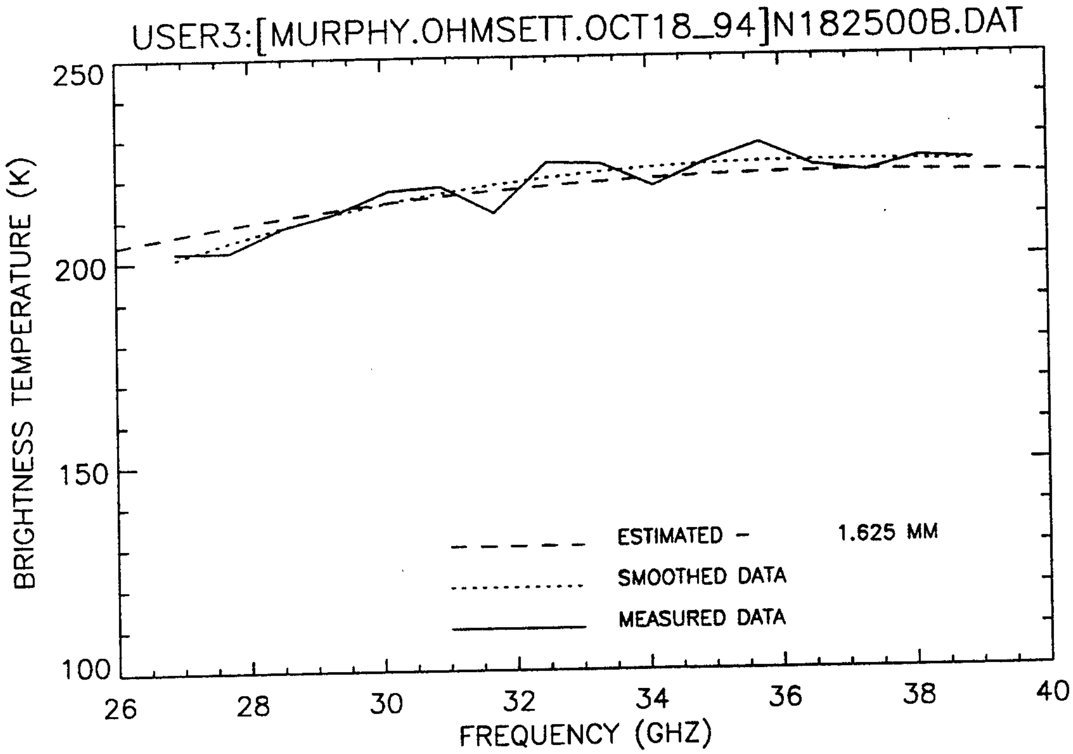

Figure E-84 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 2

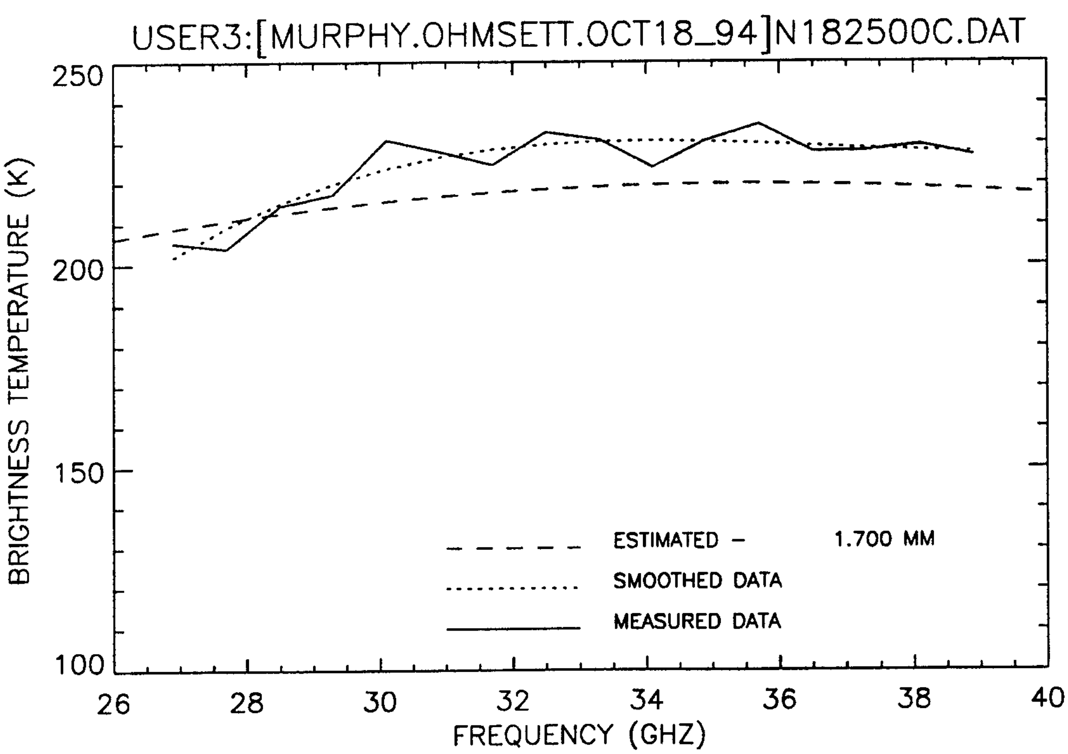

Figure E-85 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 3

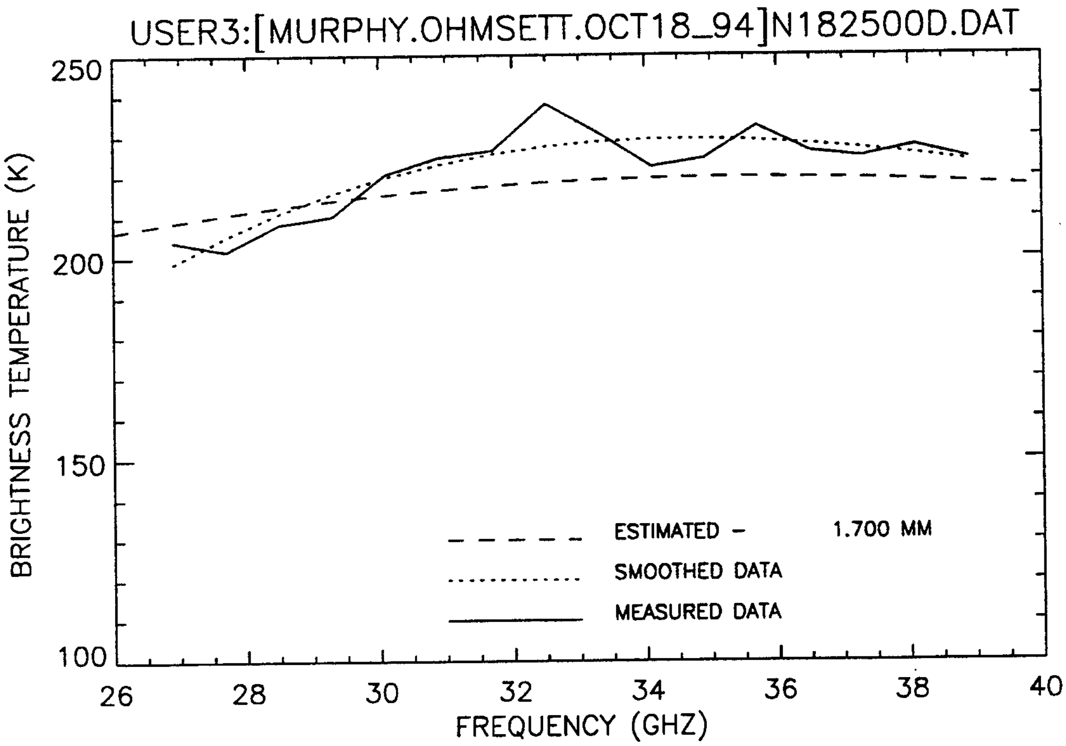

Figure E-86 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 4

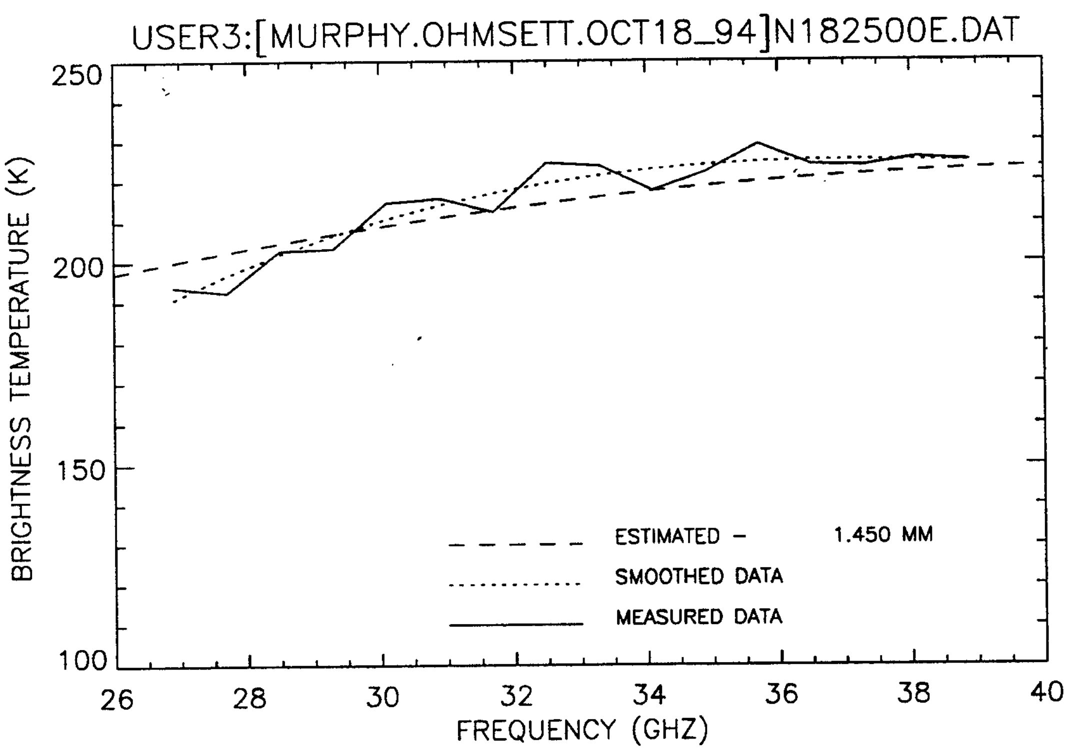

Figure E-87 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 5

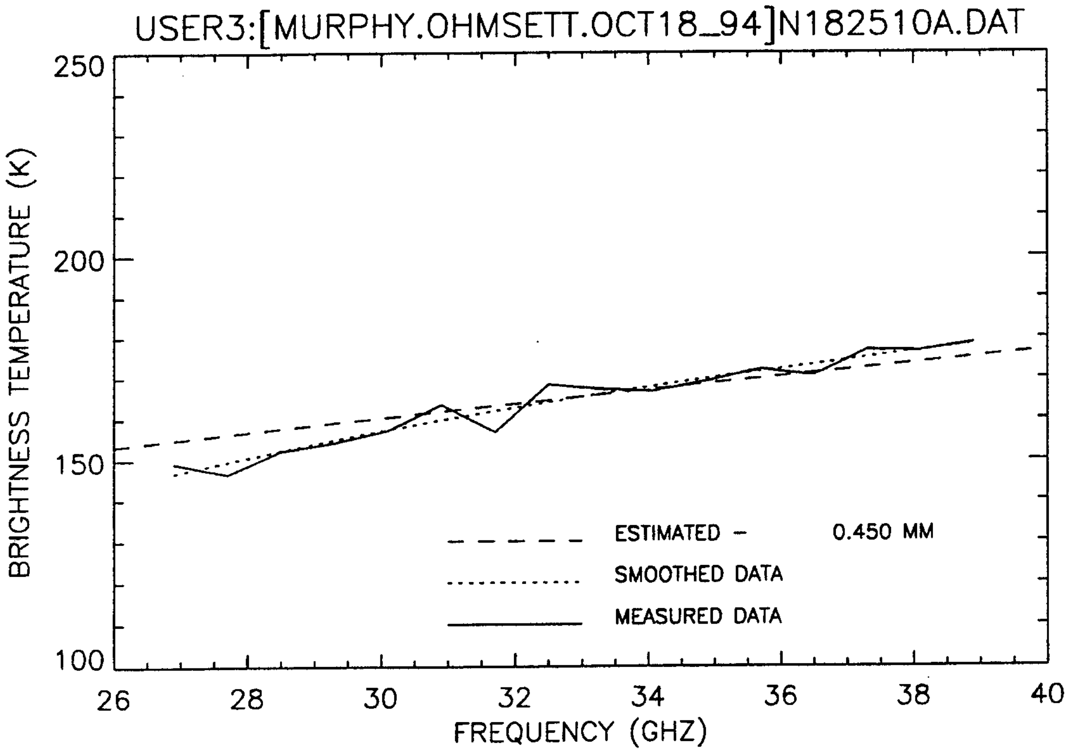

Figure E-88 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 1

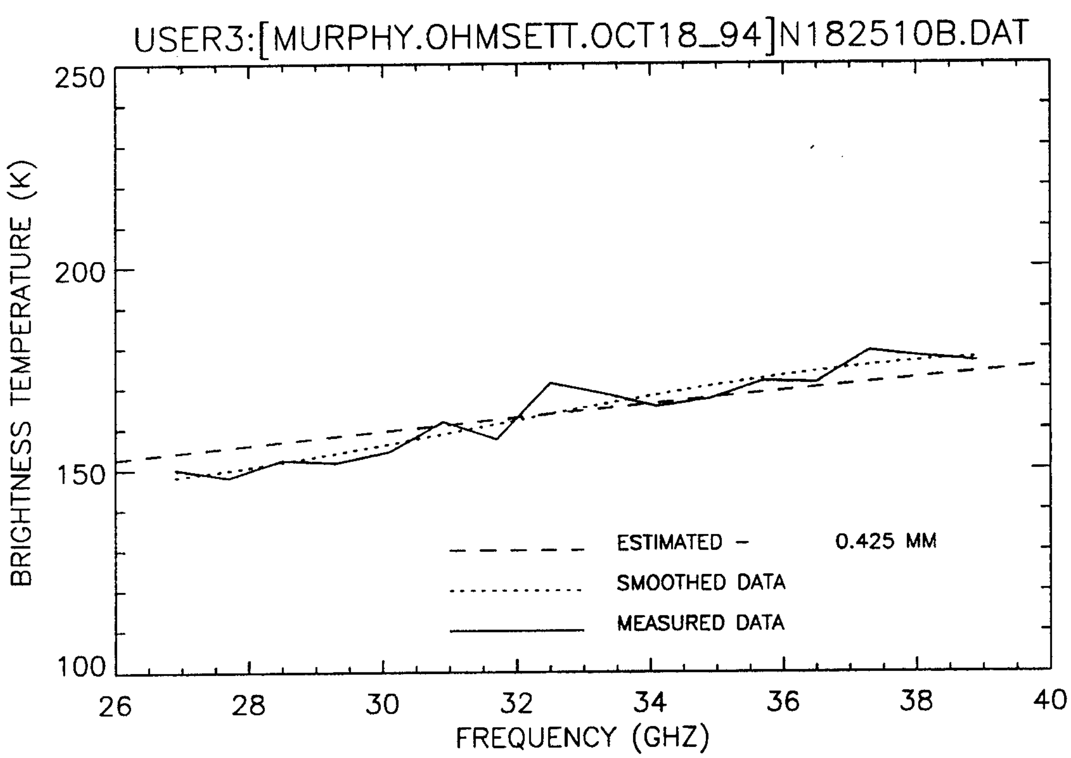

Figure E-89 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 2

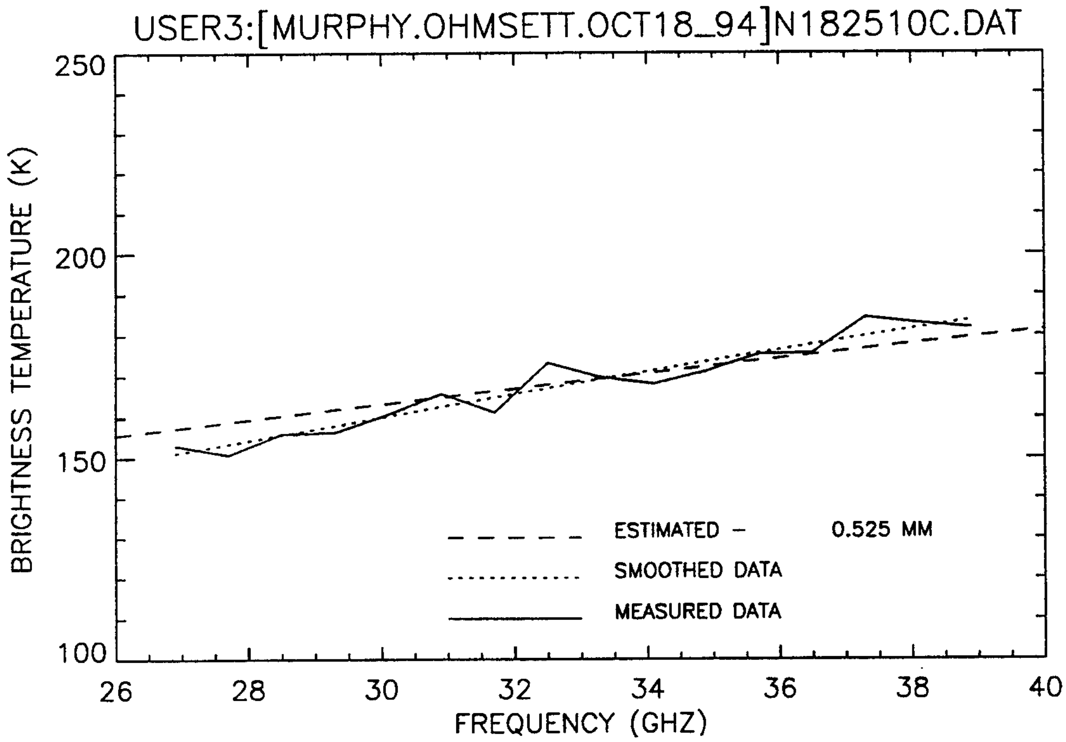

Figure E-90 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 3

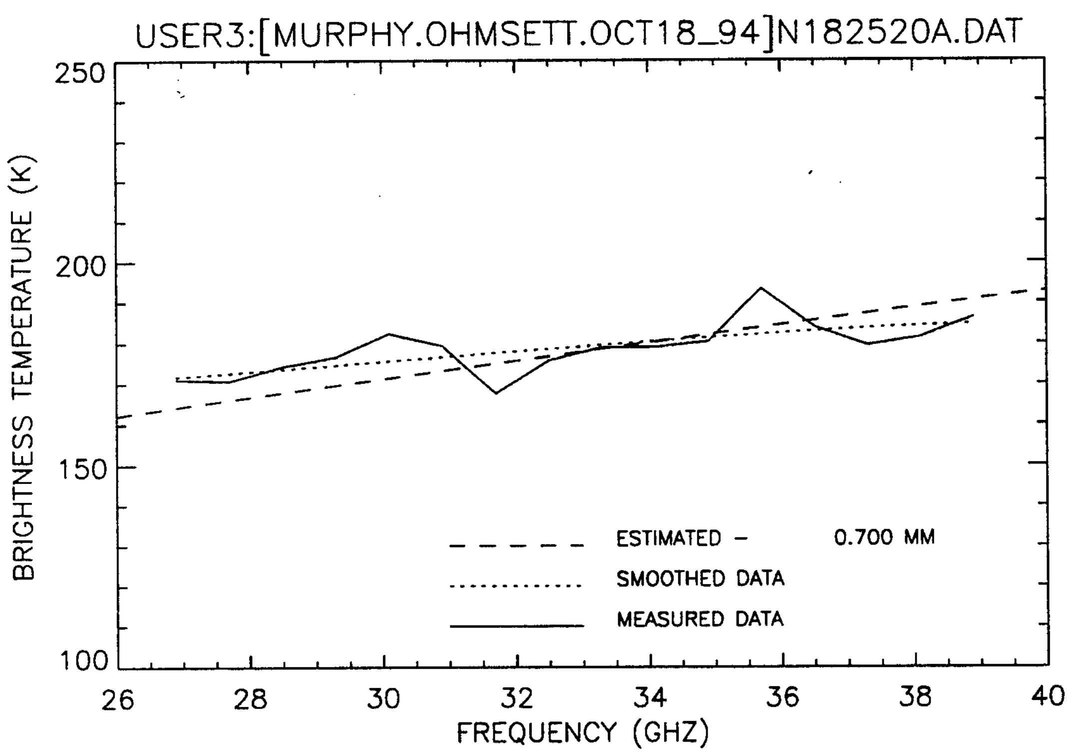

Figure E-91 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 1

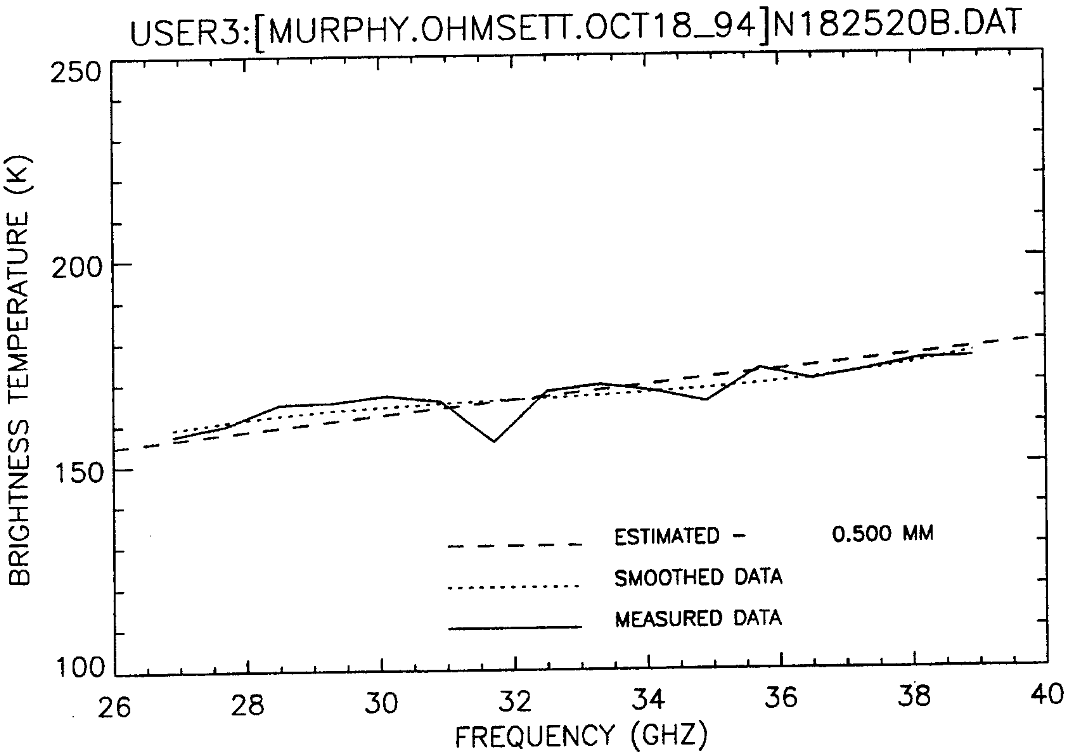

Figure E-92 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 2

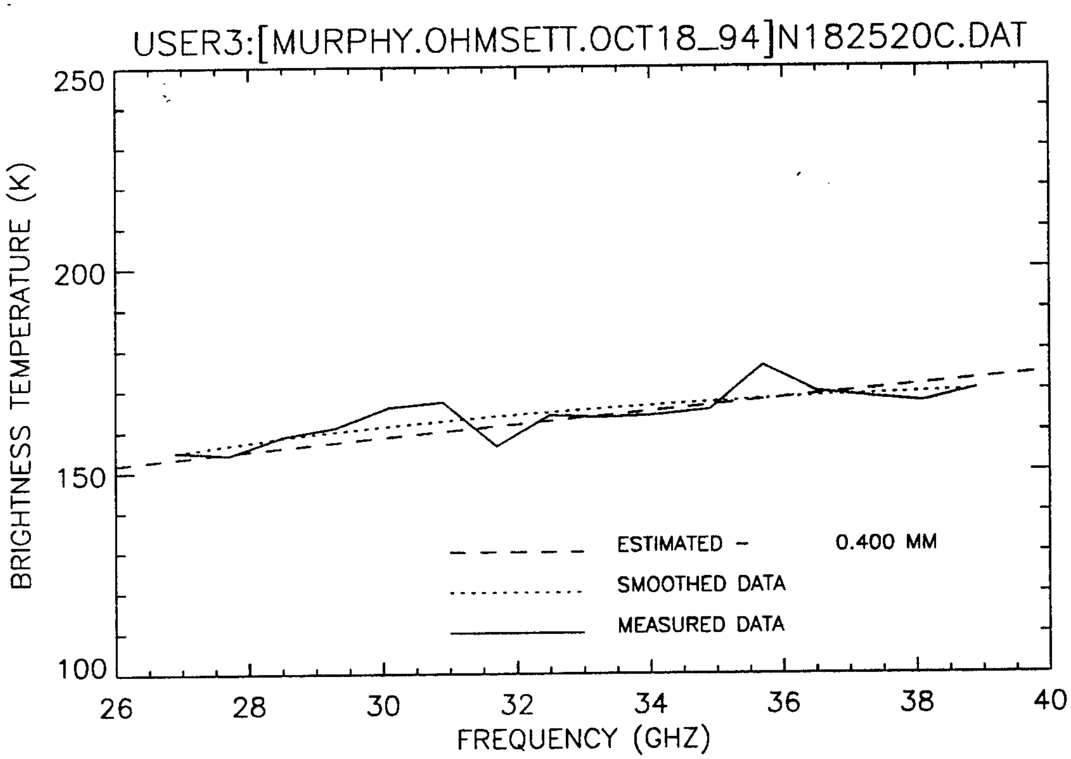

Figure E-93 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 3

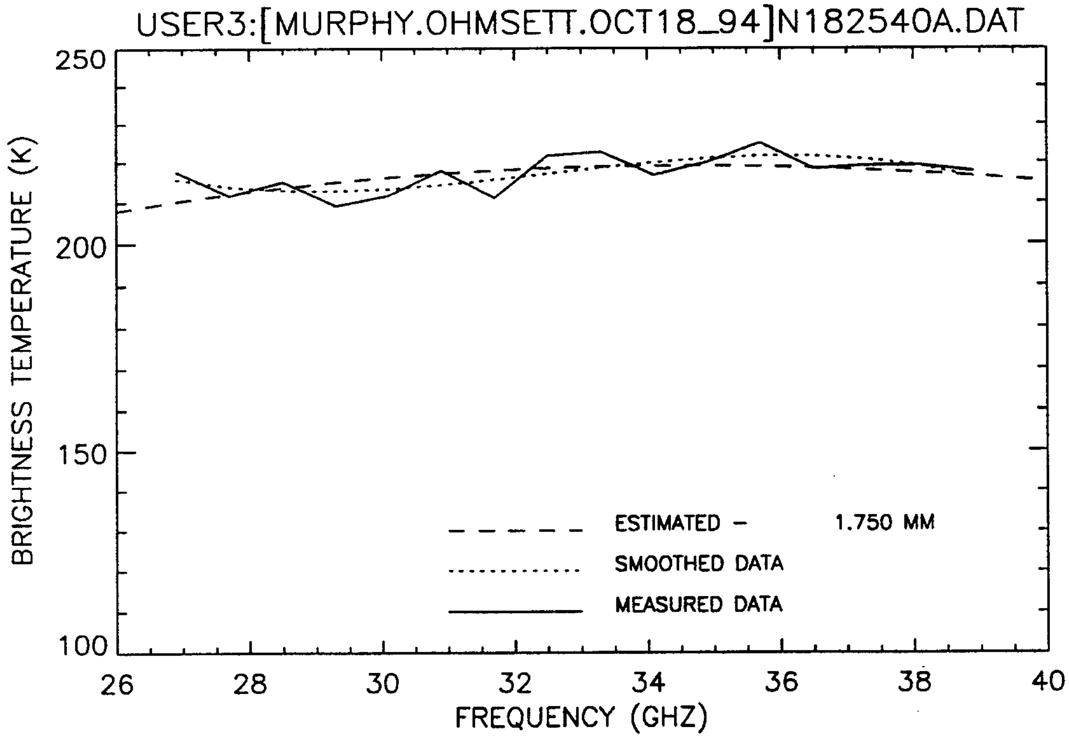

Figure E-94 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 1

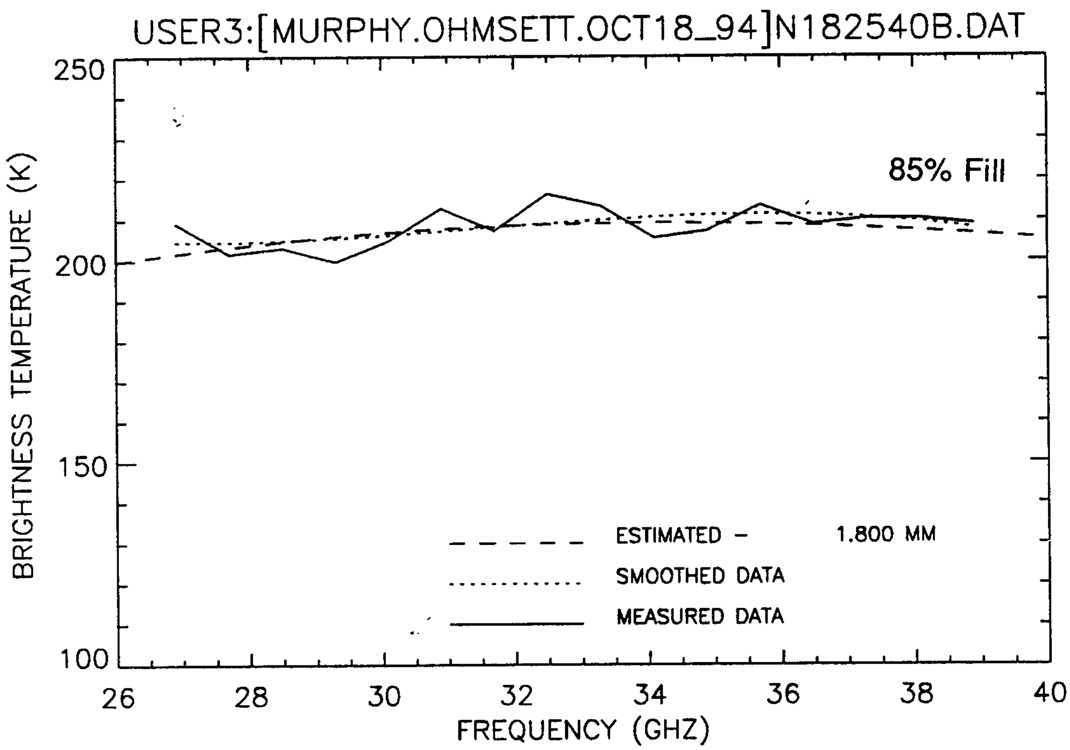

Figure E-95 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 2

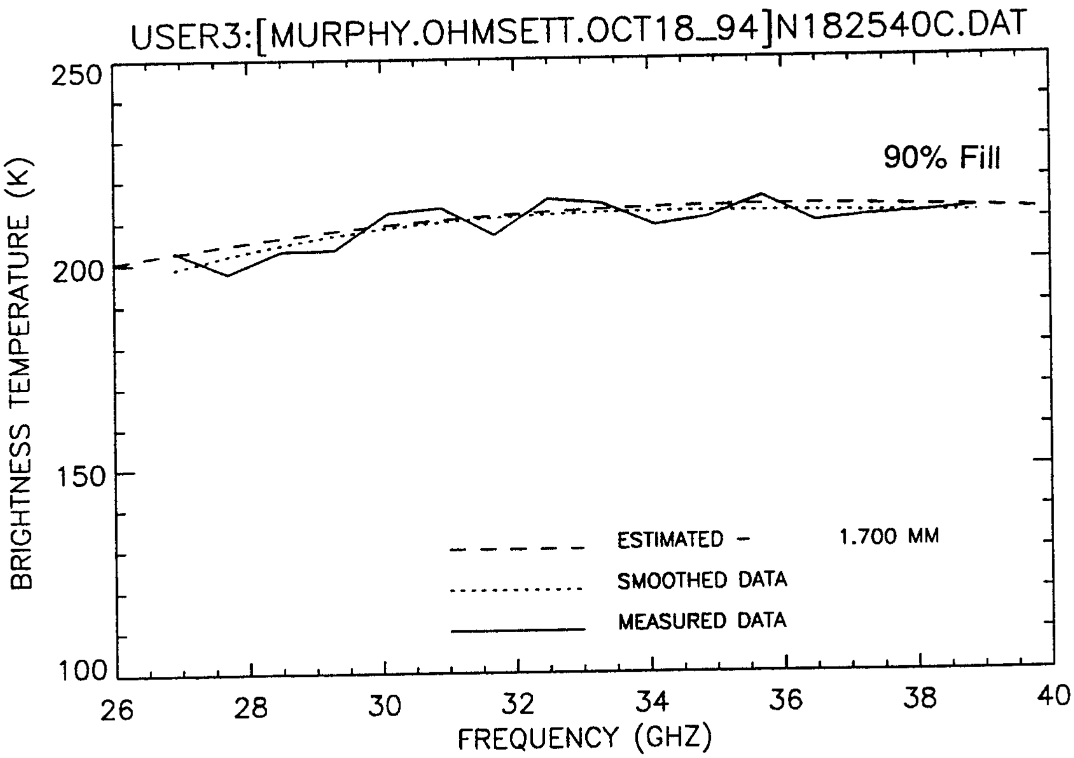

Figure E-96 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 3

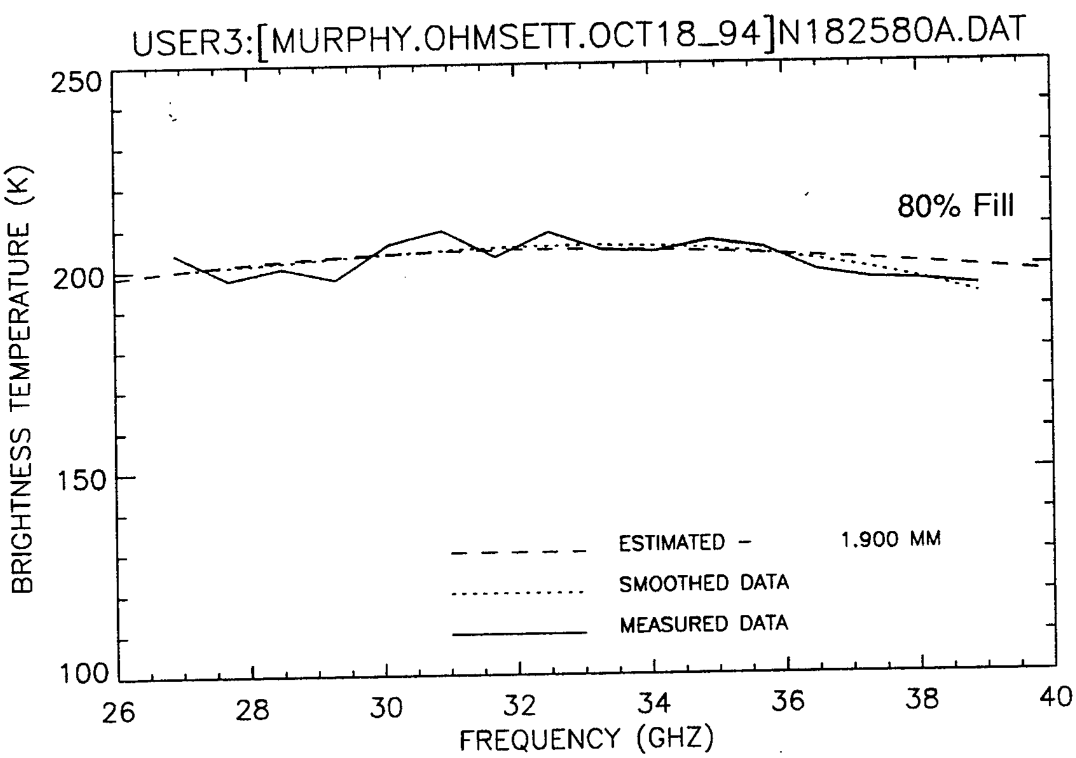

Figure E-97 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 1

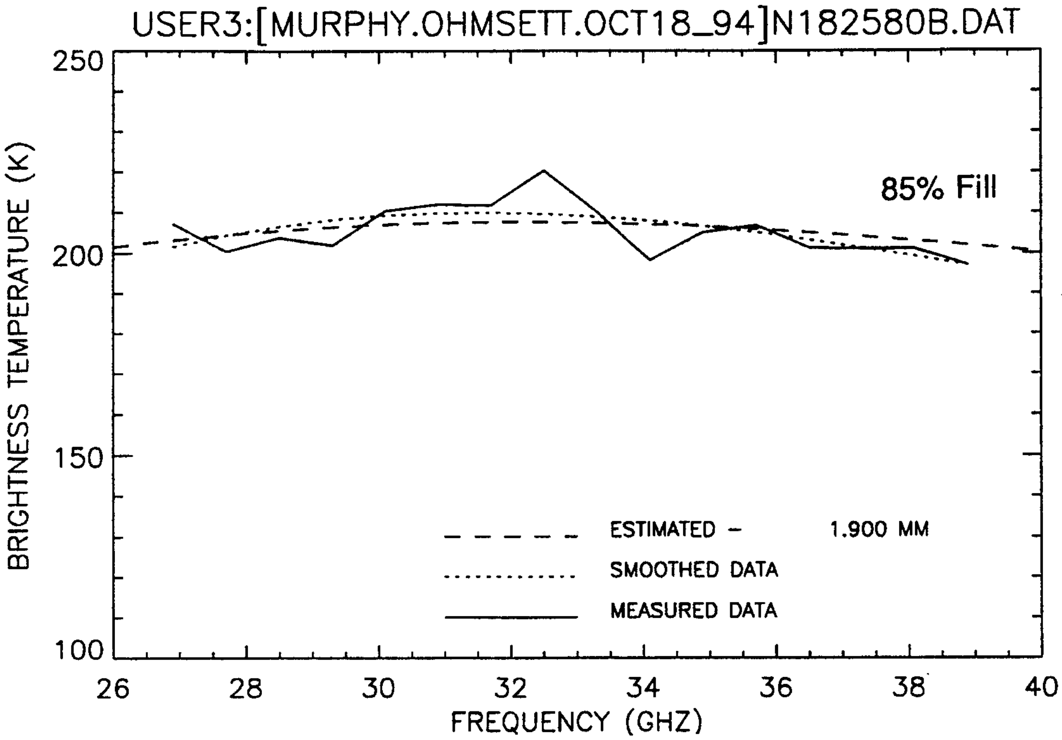

Figure E-98 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 2

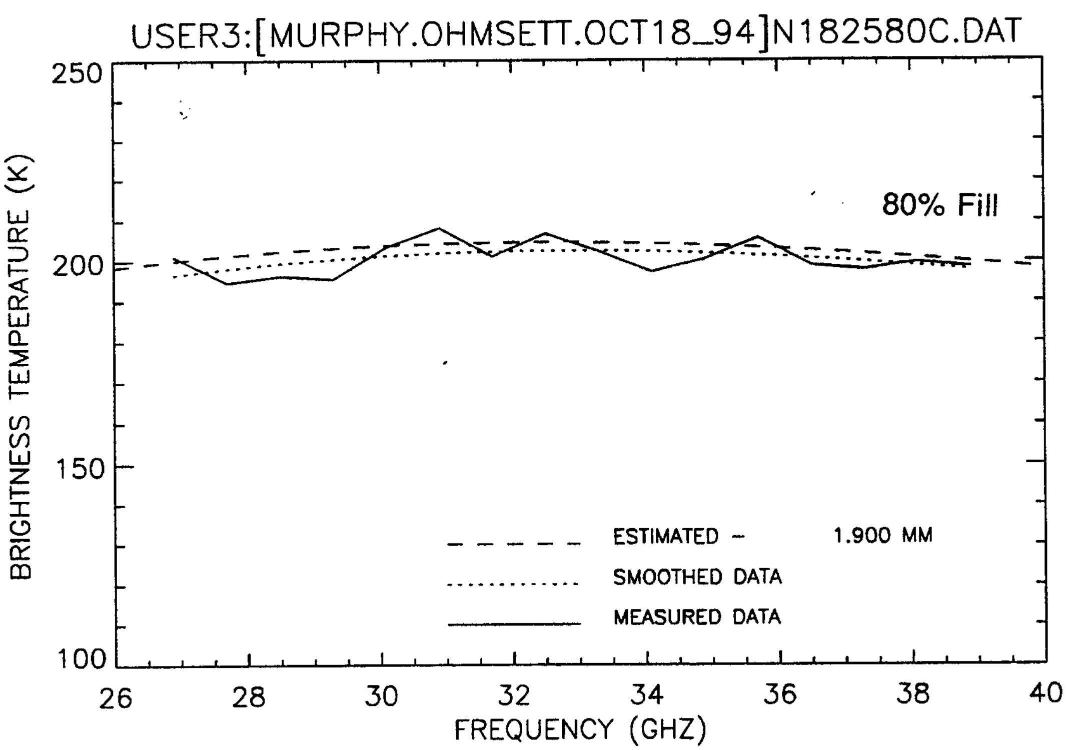

Figure E-99 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 3

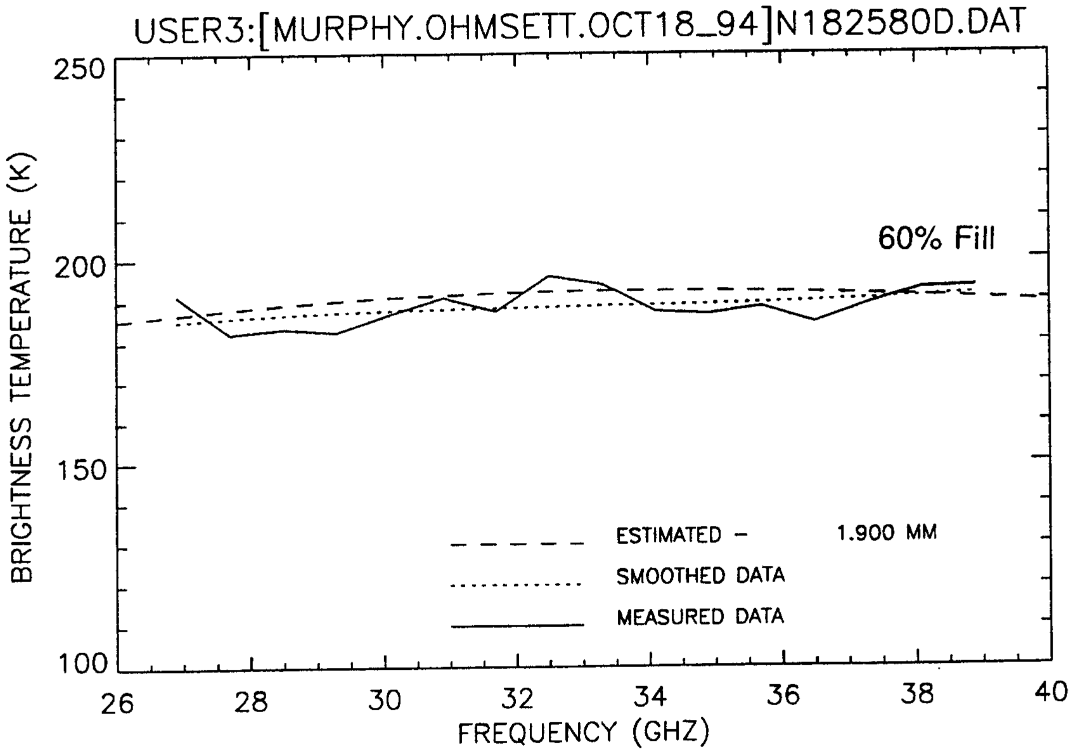

Figure E-100 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 4

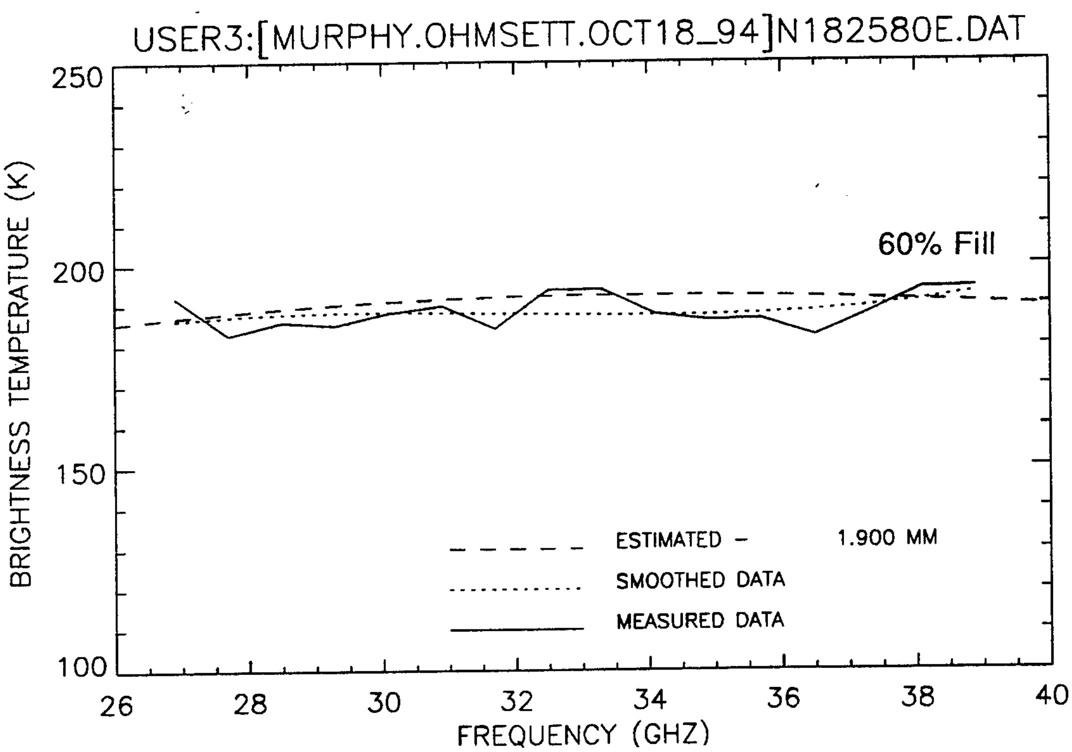

Figure E-101 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, Wave Condition 1, 18 October 1994, Pass 5

The wave generator was reset to create wave condition 2. Data collection commenced over the clean water pool after the waves had reached steady state.

P180000A - This curve was chosen as the water background reference for this set of measurements. The measured data points seem to exhibit a somewhat noisy characteristic. This may be due to sun glinting effects from the surface of the water.

P180000B - This curve is a good match to the algorithm estimate of 0.000 mm.

P180000C - This curve is a fair match to the algorithm estimate of 0.000 mm.

The main bridge was positioned over the 2.5 mm, 100% coverage oil target. At this point all of the oil targets contained bubbles on the oil surface. The oil had a "swirly" appearance which was assumed to be due to oil and water mixing to create an emulsion.

P182500A - This curve is a poor match to the algorithm estimate of 1.675 mm. The high overall T^B indicates an emulsion.

P182500B - This curve is a poor match to the algorithm estimate of 1.675 mm. The high overall T^B indicates an emulsion.

P182500C - This curve is a poor match to the algorithm estimate of 1.675 mm. The high overall T^B indicates an emulsion.

The main bridge as positioned over the 2.5 mm, 10% coverage oil target. The first measurement had a beam fill of approximately 20% while the second and third measurements had a beam fill of 35%.

P182510A - This curve is a poor match to the algorithm estimate of 0.000 mm. The shape of the curve seems to match the inflection and upsloping trait of a 3.8 mm estimate (plotted); however, the overall T^B is too low. Additionally, the measurement appears to be corrupted by noise, possibly induced by sun-glint from the water/oil surface. The result is inconclusive.

P182510B - This curve is a fair match to the algorithm estimate of 3.575 mm; however, a 3.7 mm estimate seems to be a better match to the data. This data set is also somewhat noisy.

P182510C - This curve is a good match to the algorithm estimate of 0.775 mm.

The main bridge was positioned over the 2.5 mm, 20% coverage oil target pool. The antenna beam fill is estimated to be 50%, however, as the waves pass the beam fill seems to increase to 60%.

P182520A - This curve is a fair match to the algorithm estimate of 1.675 mm; however, the overall T^B seems to be slightly higher than the estimated curve. This may indicate an emulsion.

P182520B - This curve is a fair match to the algorithm estimate of 1.650 mm; however, the overall T^B seems to be slightly higher than the estimated curve. This may indicate an emulsion.

P182520C - This curve is a fair match to the algorithm estimate of 1.800 mm; however, the overall T^B seems to be slightly lower than the estimated curve.

The main bridge was positioned over the 2.5 mm, 40% coverage oil target pool. The antenna beam fill is estimated to be 95%.

P182540A - This curve is a poor match to the algorithm estimate of 1.675 mm. The high overall T^B indicates an emulsion.

P182540B - This curve is a poor match to the algorithm estimate of 1.675 mm. The high overall T^B indicates an emulsion.

P182540C - This curve is a poor match to the algorithm estimate of 1.700 mm. The high overall T^B indicates an emulsion.

The main bridge was positioned over the 2.5 mm, 40% coverage oil target pool. The antenna beam fill is 100%

P182580A - This curve is a excellent match to the algorithm estimate of 1.325 mm, although it is a bit noisy.

P182580B - This curve is a poor match to the algorithm estimate of 1.625 mm. The high overall T^B indicates an emulsion.

P182580C - This curve is a poor match to the algorithm estimate of 1.650 mm. The high overall T^B indicates an emulsion.

The shape of these three measurements is quite similar, though there seems to be an increasing T^B offset between the three measurements. The cause for this increase in overall T^B between the measurements is unknown.

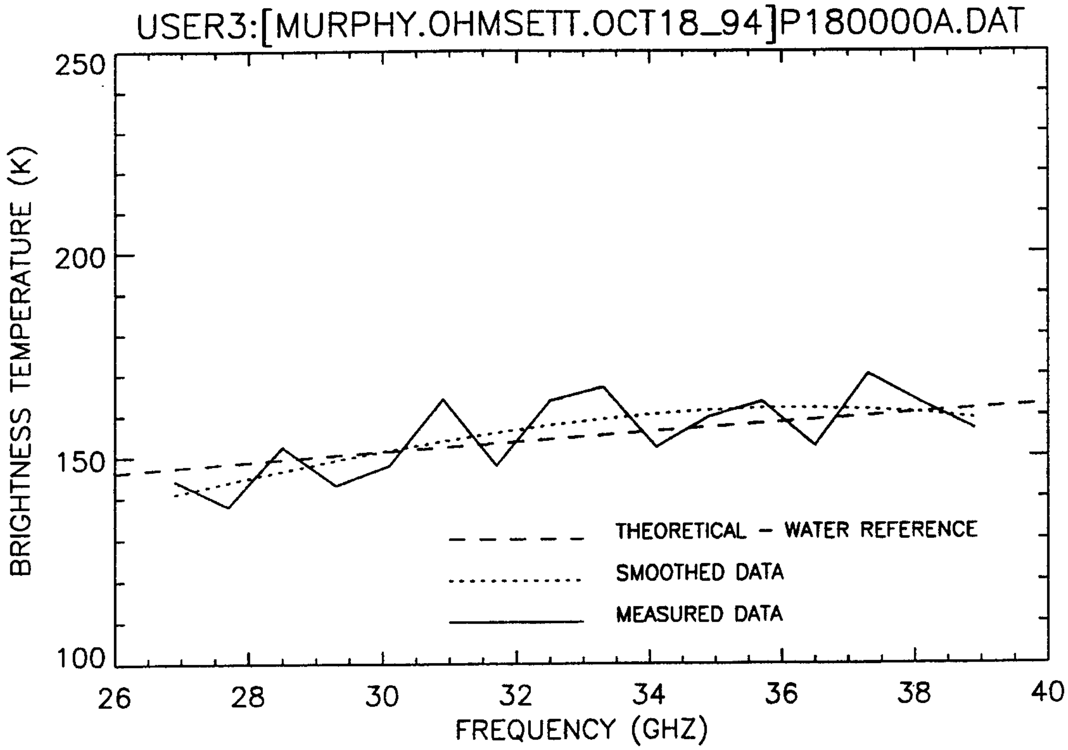

Figure E-102 T^B Versus Frequency Plot for Background Water, Wave Condition 2, 18 October 1994, Pass 1

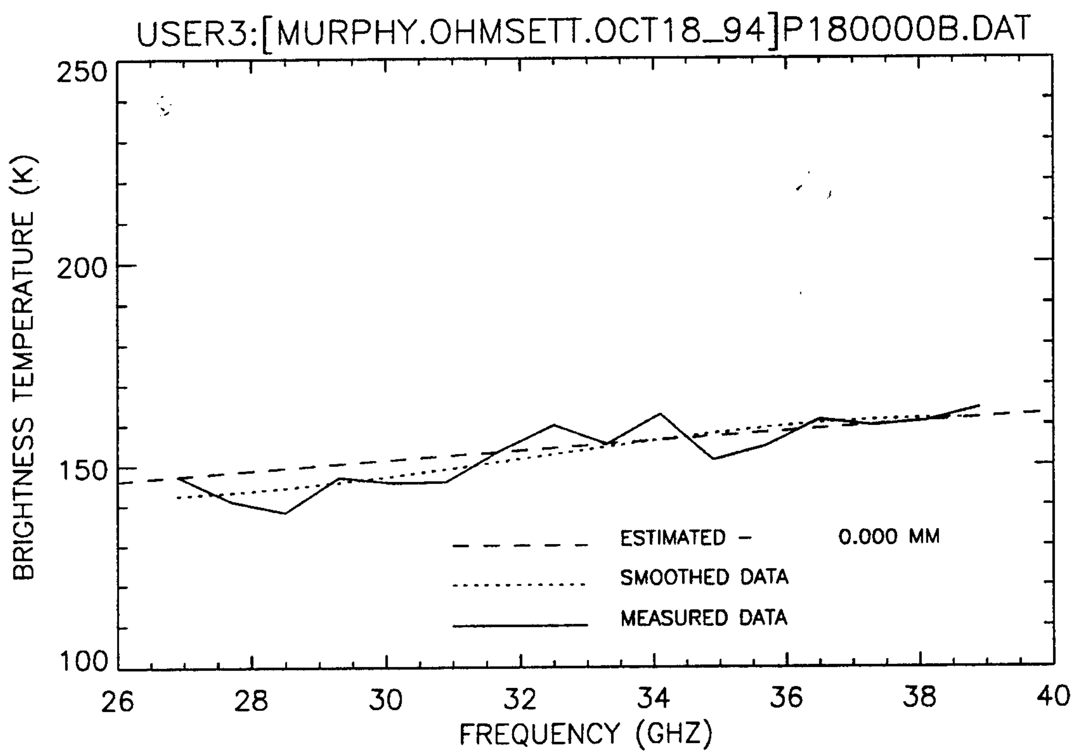

Figure E-103 T^B Versus Frequency Plot for Background Water, Wave Condition 2, 18 October 1994, Pass 2

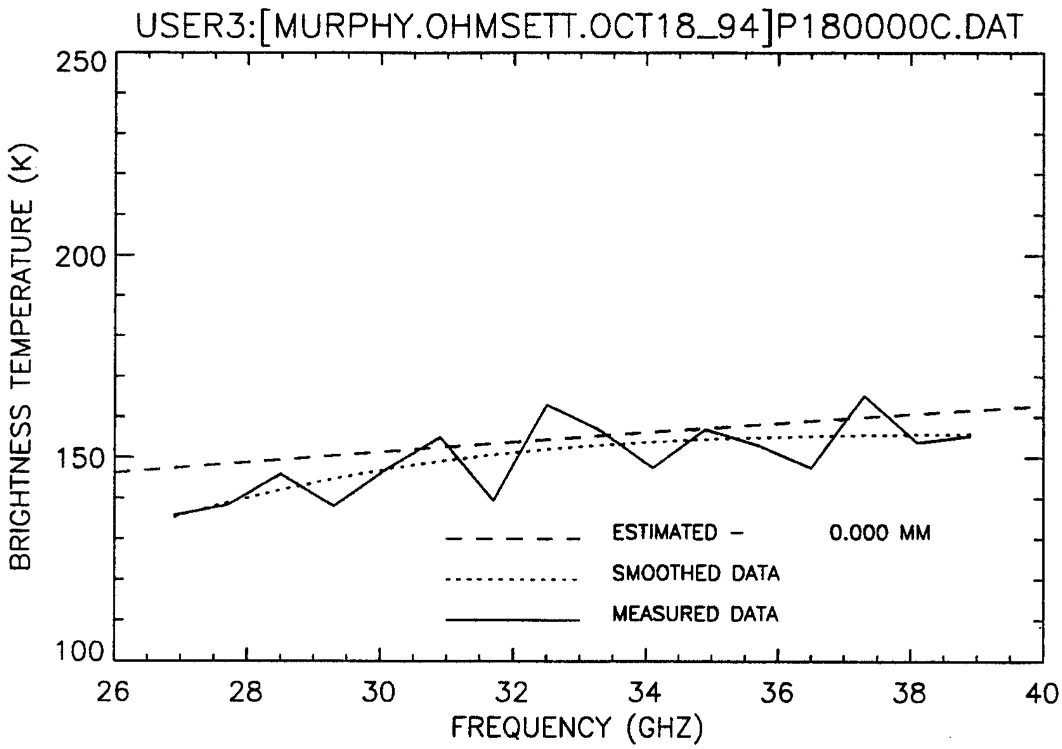

Figure E-104 T^B Versus Frequency Plot for Background Water, Wave Condition 2, 18 October 1994, Pass 3

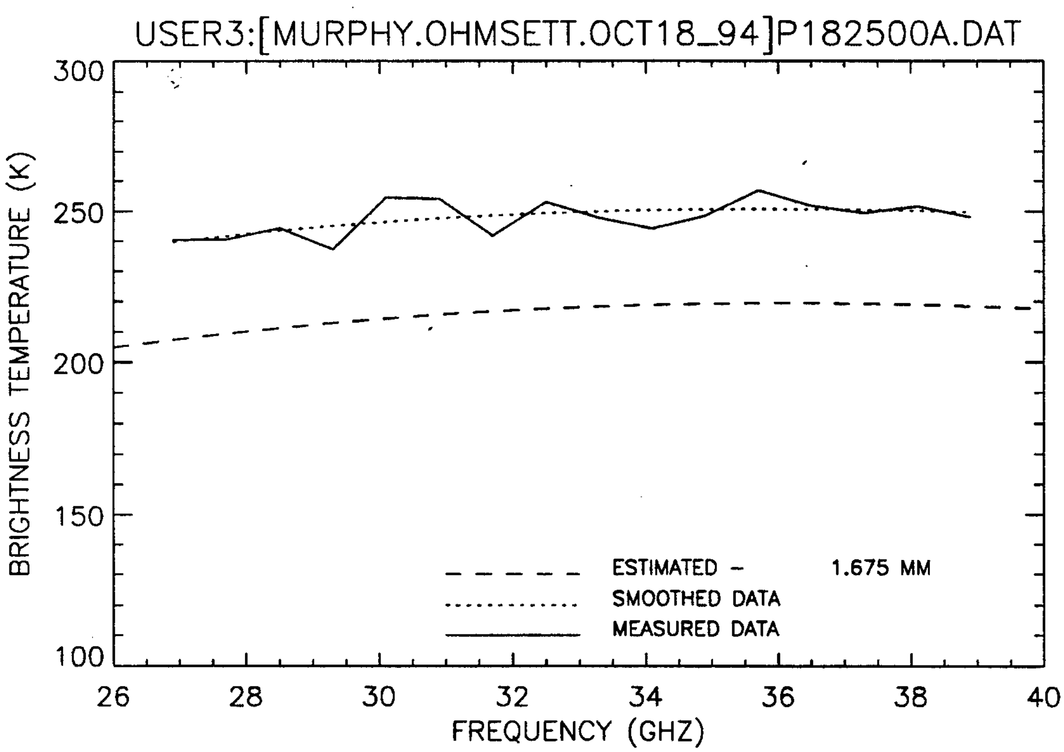

Figure E-105 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 1

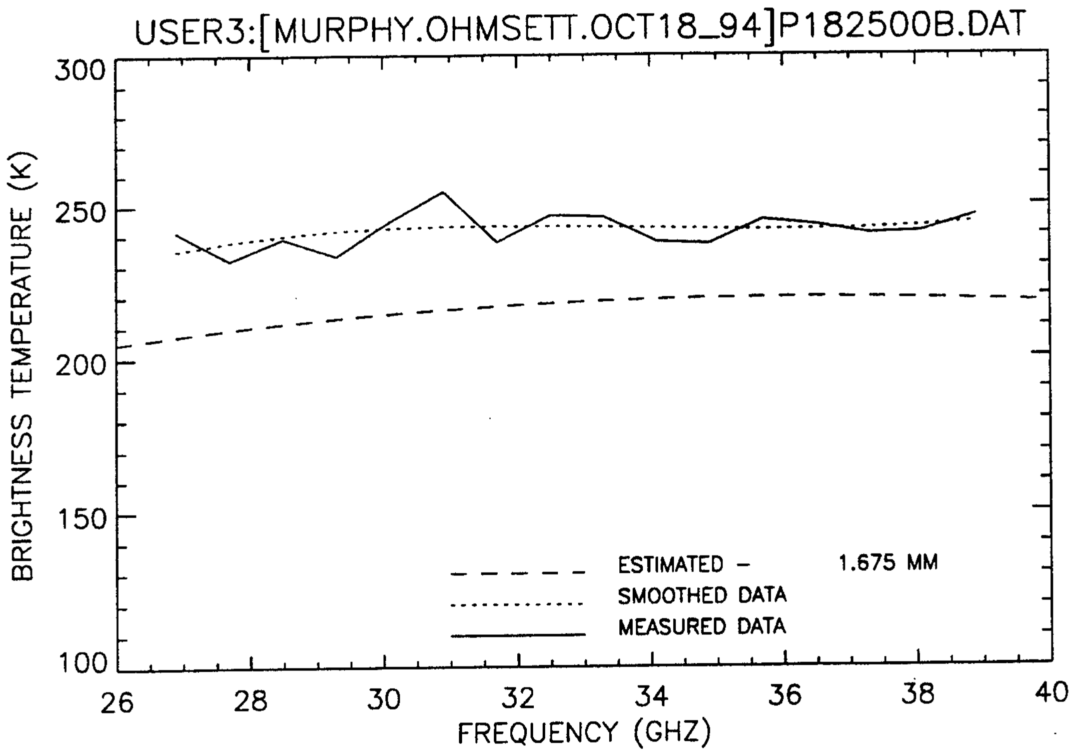

Figure E-106 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 2

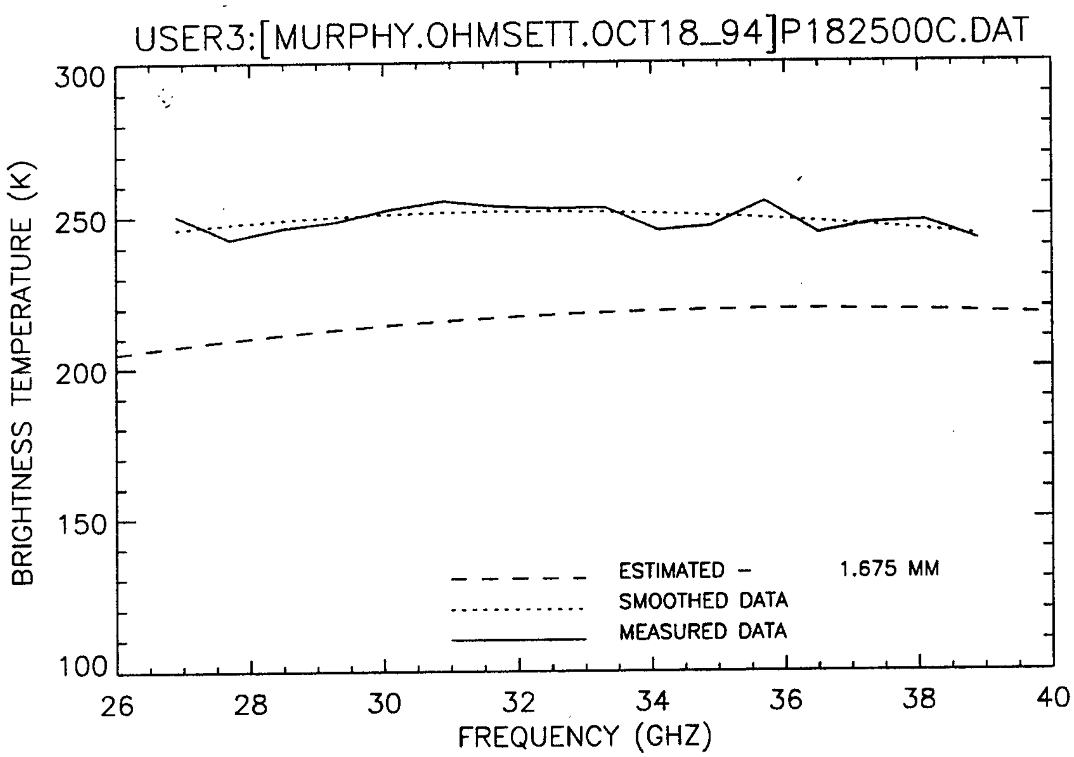

Figure E-107 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 3

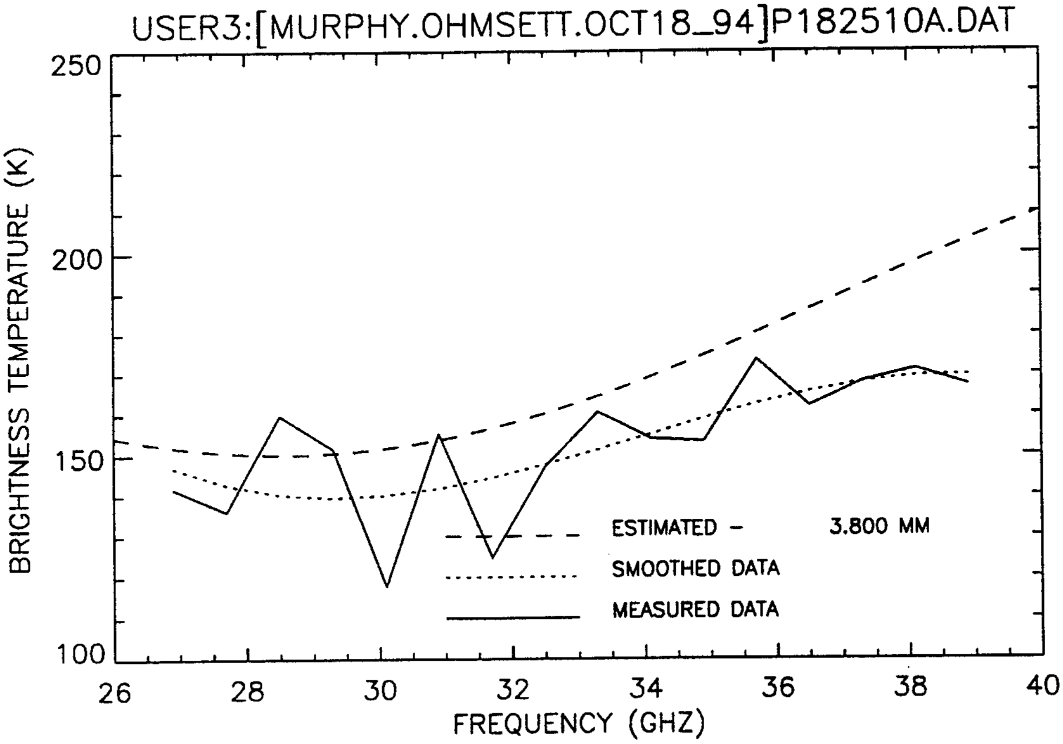

Figure E-108 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 1

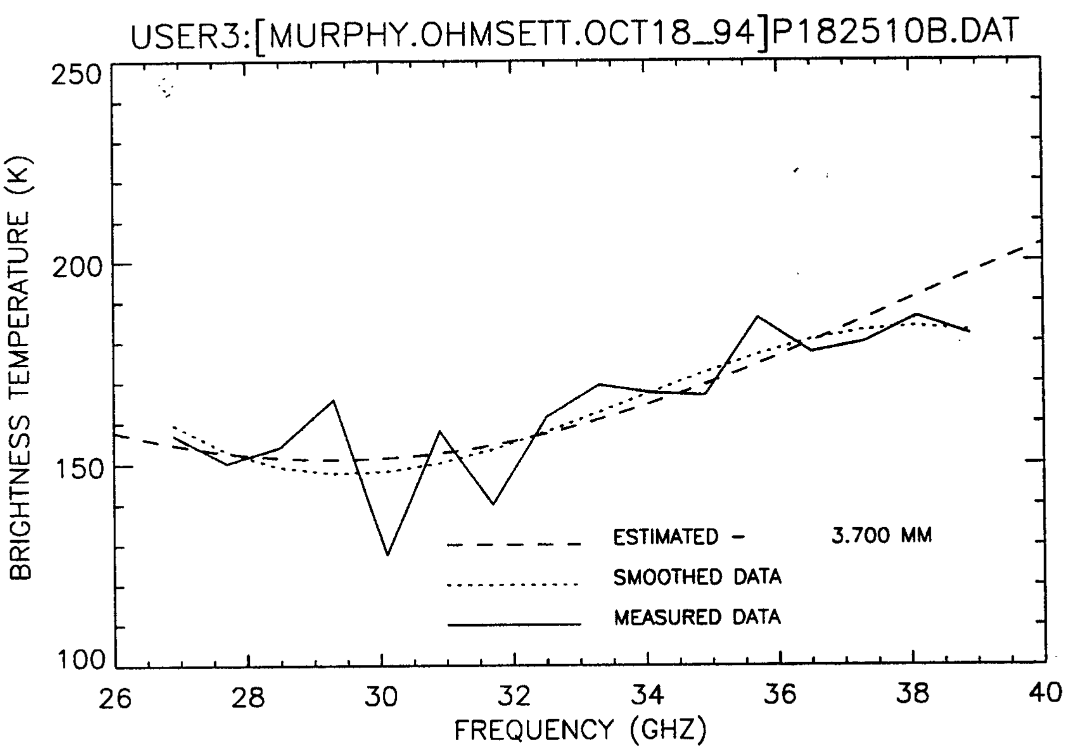

Figure E-109 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 2

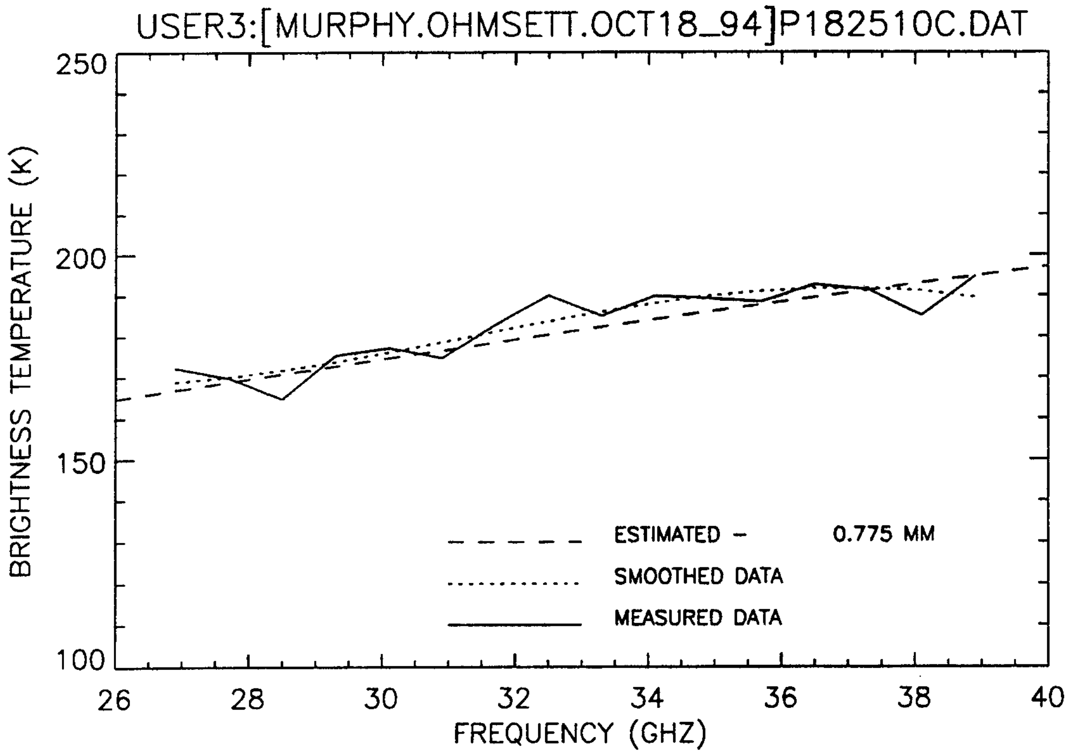

Figure E-110 T^B Versus Frequency Plot for 2.5 mm, 10% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 3

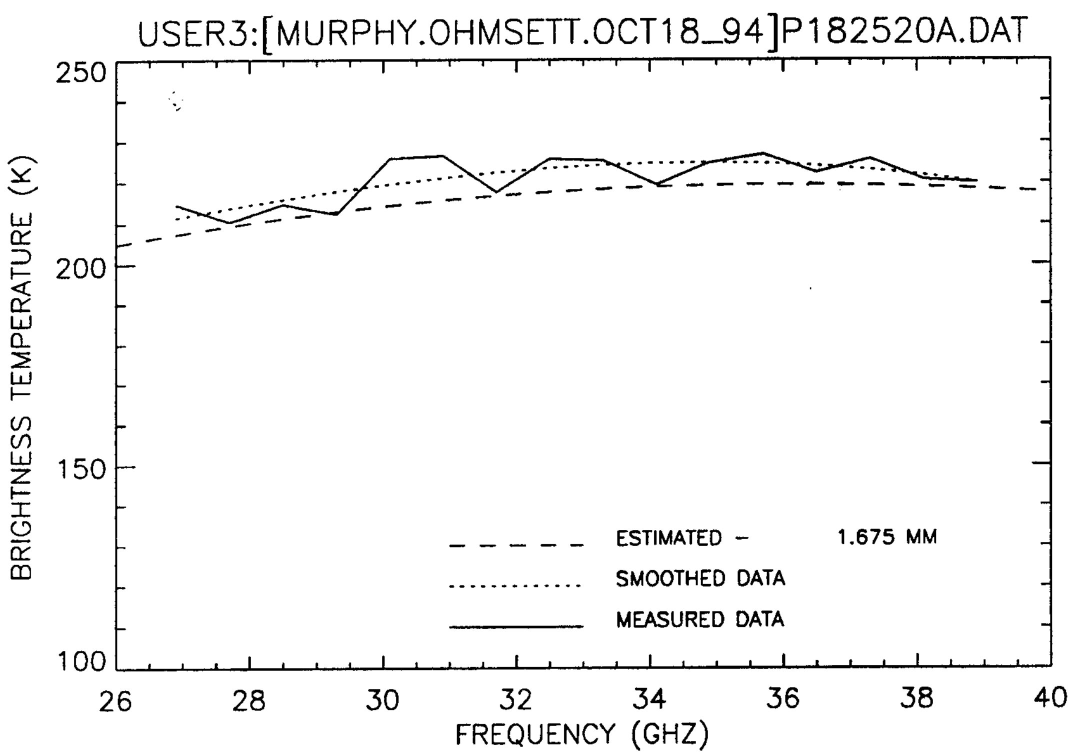

Figure E-111 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 1

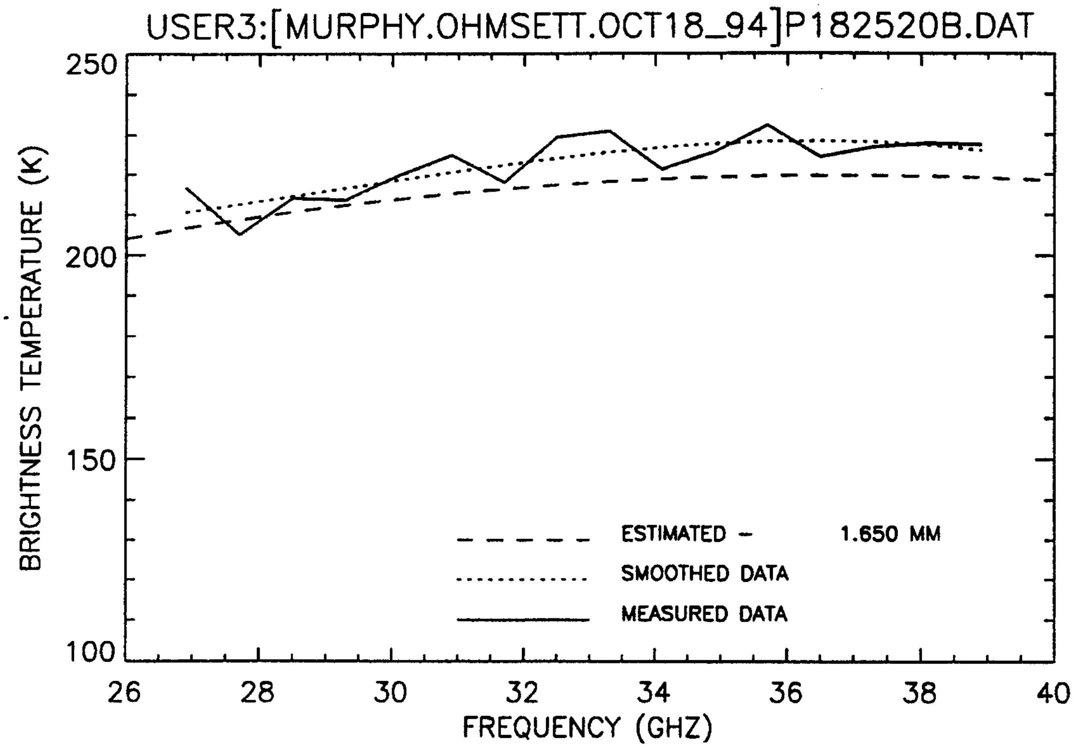

Figure E-112 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 2

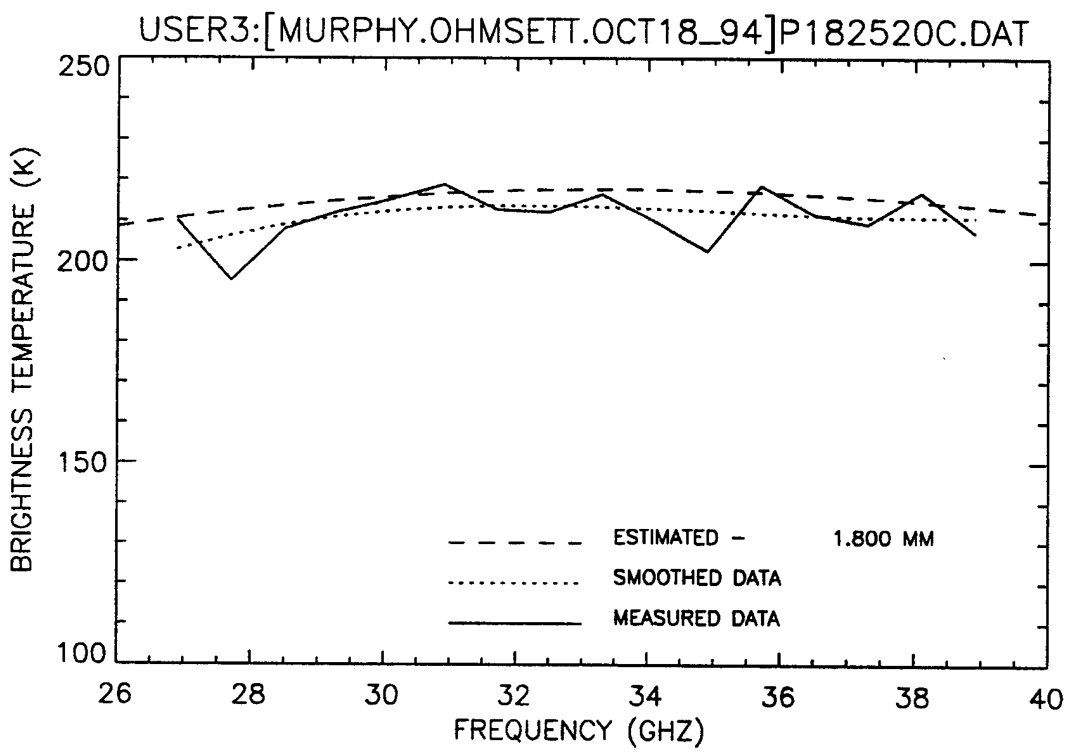

Figure E-113 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 3

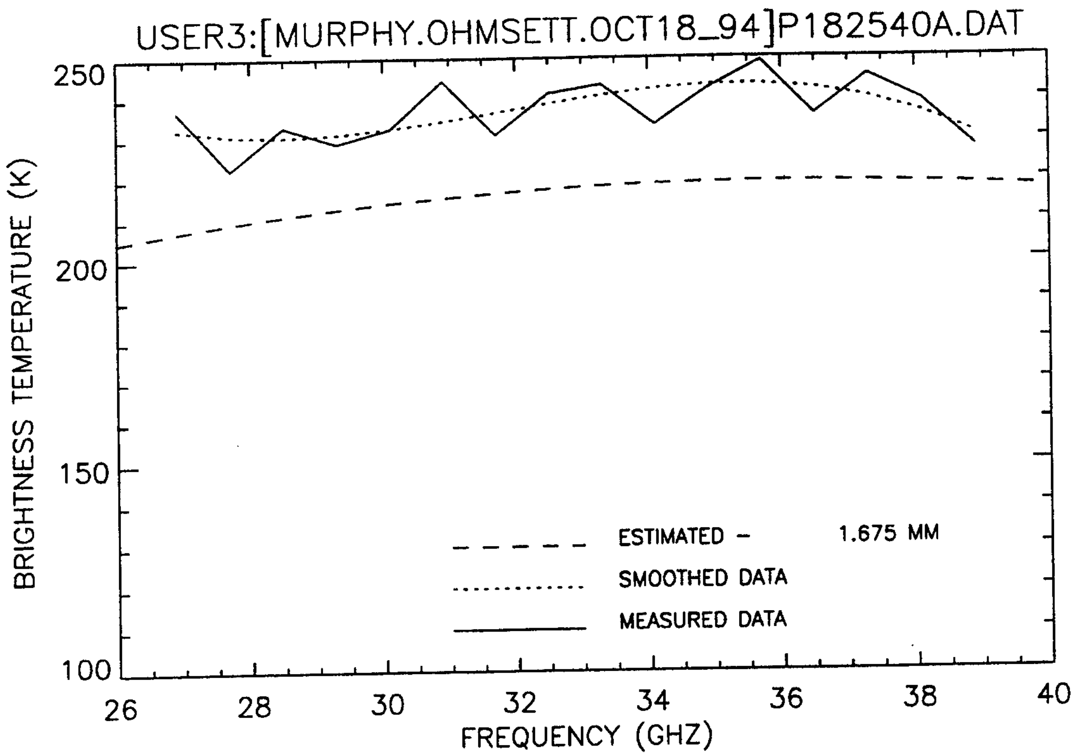

Figure E-114 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 1

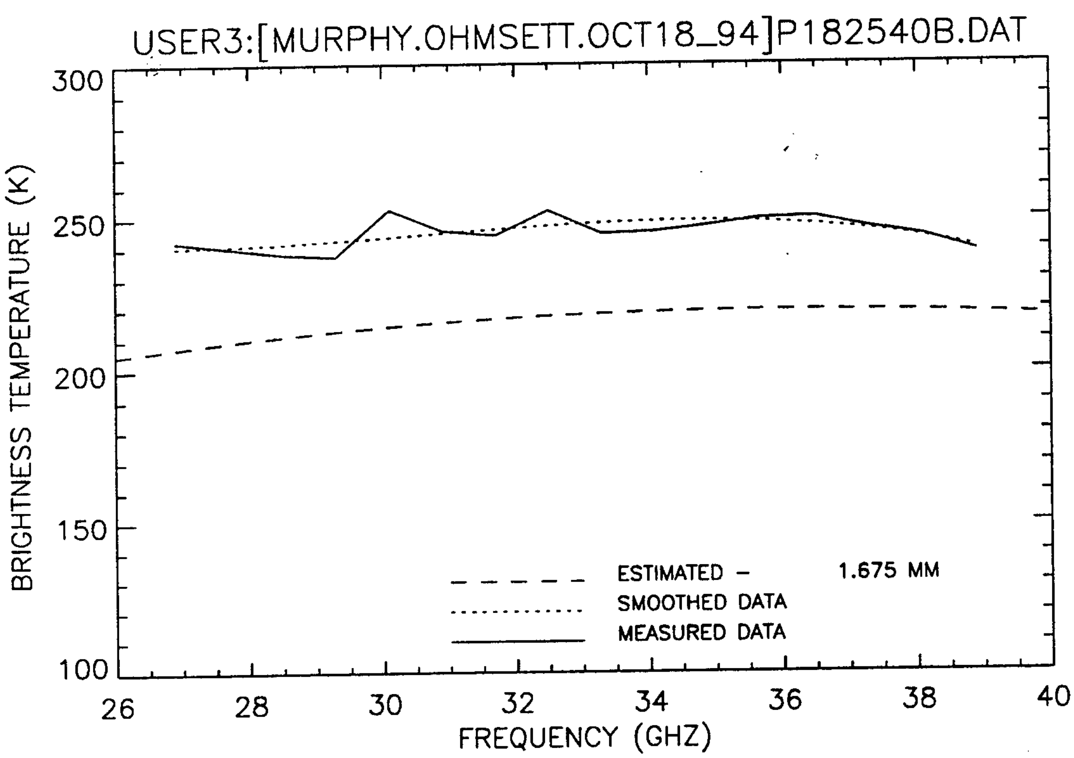

Figure E-115 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 2

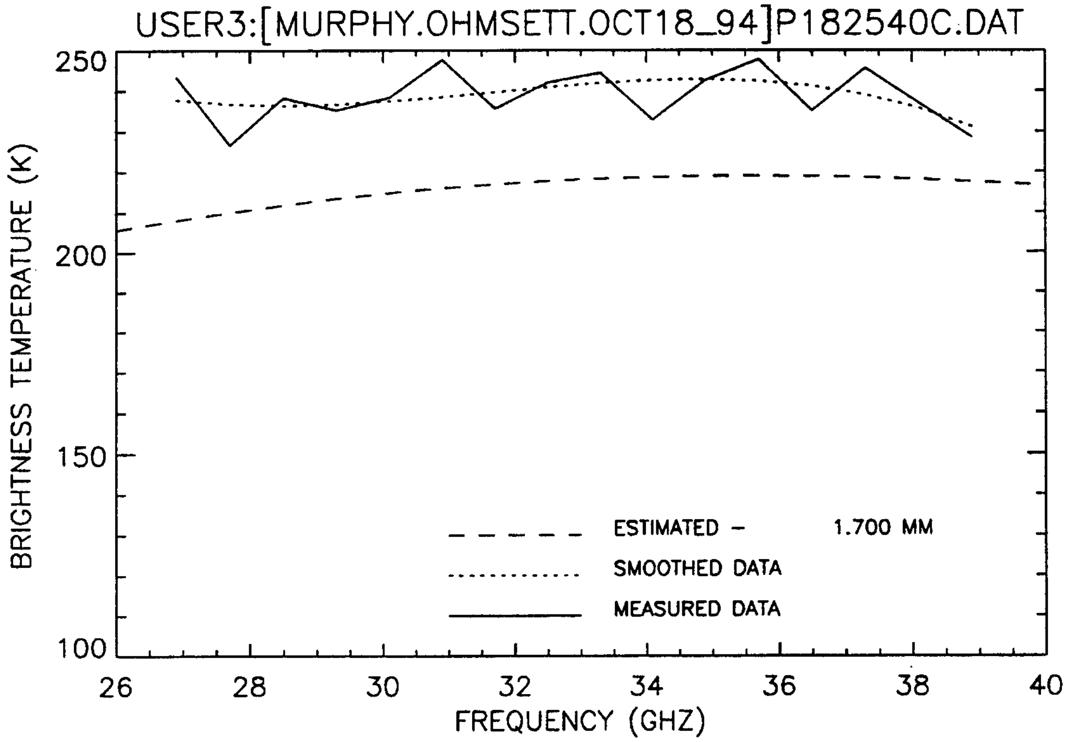

Figure E-116 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 3

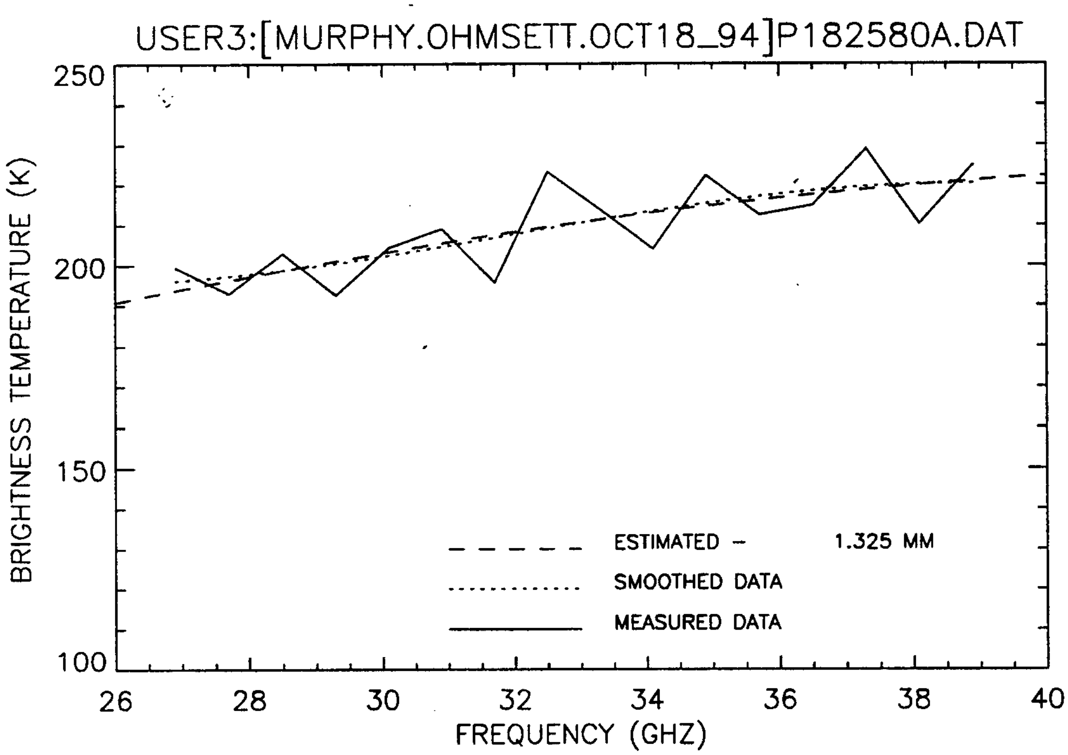

Figure E-117 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 1

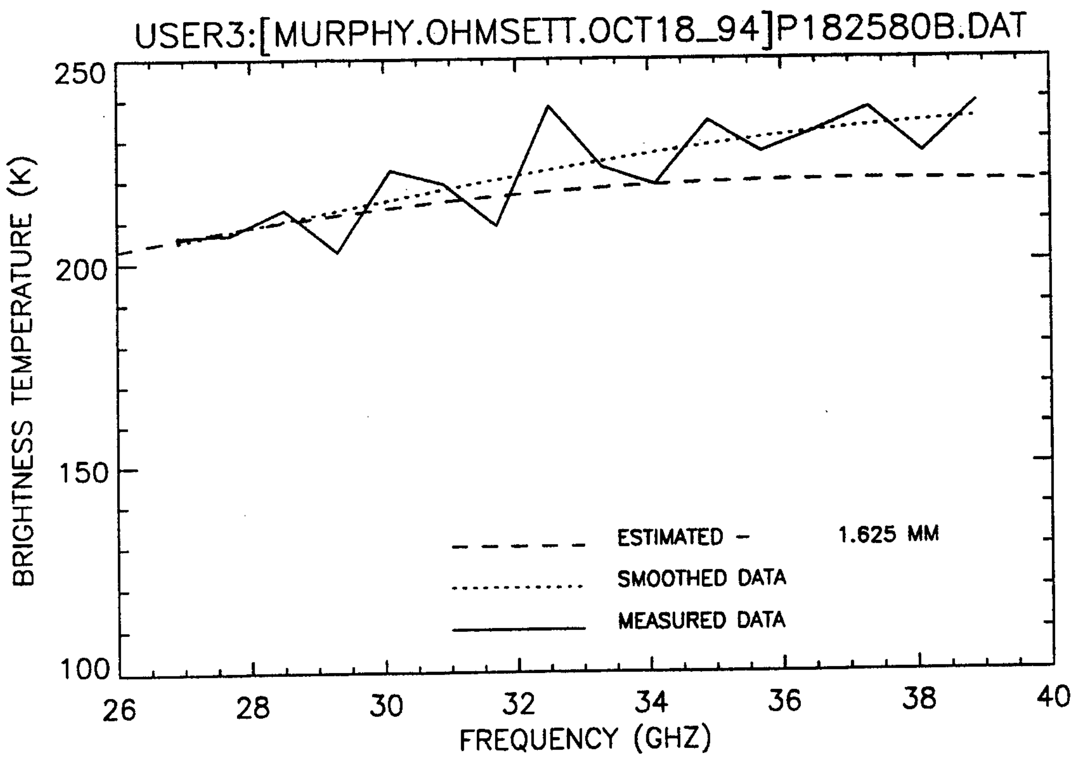

Figure E-118 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 2

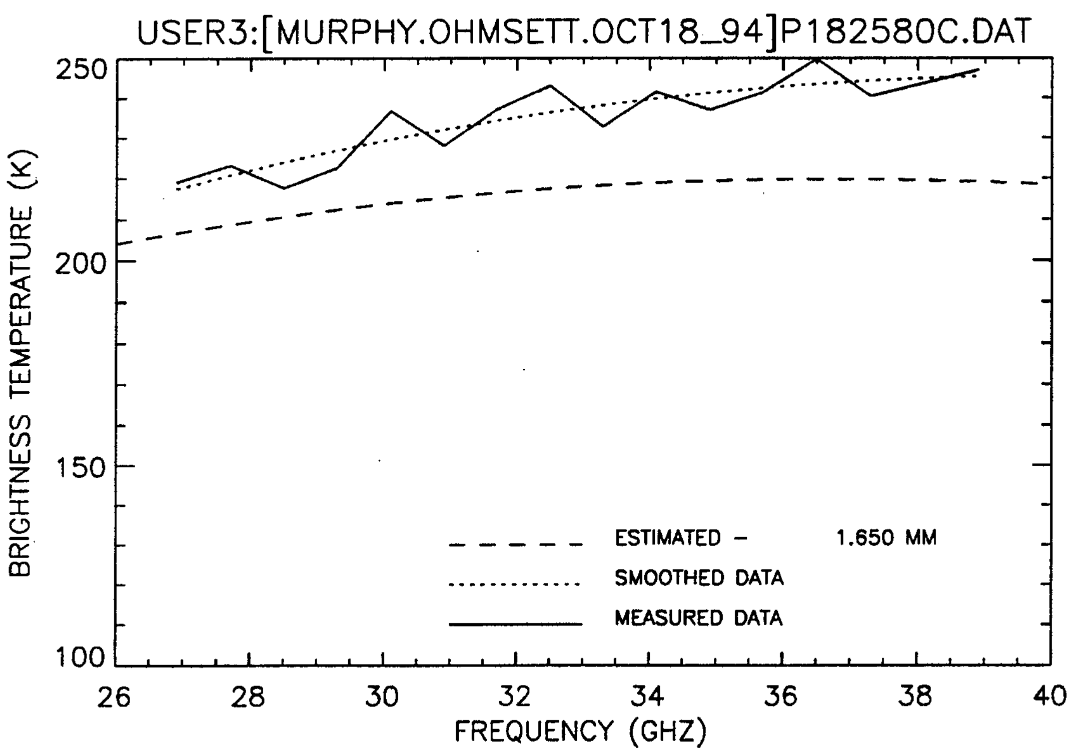

Figure E-119 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, Wave Condition 2, 18 October 1994, Pass 3

The wave generator was reset to create chop condition 2. Data collection commenced over the clean water pool after the waves had reached steady state.

Q180000A - This curve was chosen as the water background reference for this set of measurements.

Q180000B - This curve is a good match to the algorithm estimate of 0.000 mm.

Q180000C - This curve is a fair match to the algorithm estimate of 0.000 mm.

These three measurements are significantly more noisy than other water measurements. This may be due to sun glint effects from the water surface as the FSR was sampling.

In this chop condition, waves were causing small quantities of oil to escape the containment booms. The oil appears to have experienced more mixing with the water based on the different color and texture of the oil surface compared to the undisturbed uniform oil appearance.

The main bridge was positioned over the 2.5 mm, 100% coverage oil target. The oil surface, in addition to the discoloration, contained bubbles of water or air.

Q182500A - This curve is a poor match to the algorithm estimate of 1.675 mm. The high overall T^B confirms the presence of bubbles and/or emulsion.

Q182500B - This curve is a poor match to the algorithm estimate of 1.675 mm. The high overall T^B confirms the presence of bubbles and/or emulsion.

Q182500C - This curve is a poor match to the algorithm estimate of 1.675 mm. The high overall T^B confirms the presence of bubbles and/or emulsion..

The main bridge was positioned over the 2.5 mm, 20% coverage oil target. The beam fill is estimated to be 20 - 30%.

Q182520A - This curve is a good match to the algorithm estimate of 3.675 mm. Large variations in the measured T^B from 36 - 40 GHz may have caused excess modulation in the smoothed curve.

Q182520B - This curve is a good match to the algorithm estimate of 0.675 mm.

Q182520C - This curve is a good match to the algorithm estimate of 0.450 mm.

The main bridge was positioned over the northern part of the 2.5 mm, 100% coverage oil target. The antenna beam fill is estimated to be 50% for the first two measurements, 90% for the third measurement.

Q182540A - This curve is a poor match to the algorithm estimate of 0.800 mm. The sinusoidal variation seen in the smoothed curve is probably caused by the large peak-to-valley swings (noise or sun glint induced) in the measured data. The result is inconclusive.

Q182540B - This curve is a fair match to the algorithm estimate of 1.325 mm.

Q182540C - This curve is a poor match to the algorithm estimate of 1.650 mm. The high overall T^B indicates the presence of bubbles and/or emulsion. The success in estimating the previous measurement (Q182540B) may be due to partial antenna beam fill effects with an emulsion in the antenna footprint.

The main bridge was positioned over the 2.5 mm, 80% coverage oil target. All of the measurements have 90% to 100% antenna beam fill. All of the measurements have a consistent curve shape, and appear to contain bubbles and/or emulsions.

Q182580A - This curve is a poor match to the algorithm estimate of 1.700 mm. The curve has a shape similar to a 2.2 mm estimate (plotted); however, the high overall T^B confirms the presence of bubbles and/or emulsion.

Q182580B - This curve is a poor match to the algorithm estimate of 1.675 mm. The curve has a shape similar to a 1.9 mm estimate (plotted); however, the high overall T^B confirms the presence of bubbles and/or emulsion.

Q182580C - This curve is a poor match to the algorithm estimate of 1.675 mm. The high overall T^B confirms the presence of bubbles and/or emulsion.

Q182580D - This curve is a poor match to the algorithm estimate of 1.675 mm. The high overall T^B confirms the presence of bubbles and/or emulsion.

Q182580E - This curve is a poor match to the algorithm estimate of 1.675 mm. The high overall T^B confirms the presence of bubbles and/or emulsion.

As an interesting exercise, the main bridge was positioned over some tar balls that had escaped the containment booms. The antenna beam fill was estimated to be 20%.

Q18XXXXA - This curve is a good match to the algorithm estimate of 0.400 mm. The large noise component may be due to sun glint effects from the wave surfaces.

Q18XXXXB - This curve is a good match to the algorithm estimate of 0.350 mm. The large noise component may be due to sun glint effects from the wave surfaces.

Q18XXXXC - This curve is a good match to the algorithm estimate of 0.550 mm. The large noise component may be due to sun glint effects from the wave surfaces.

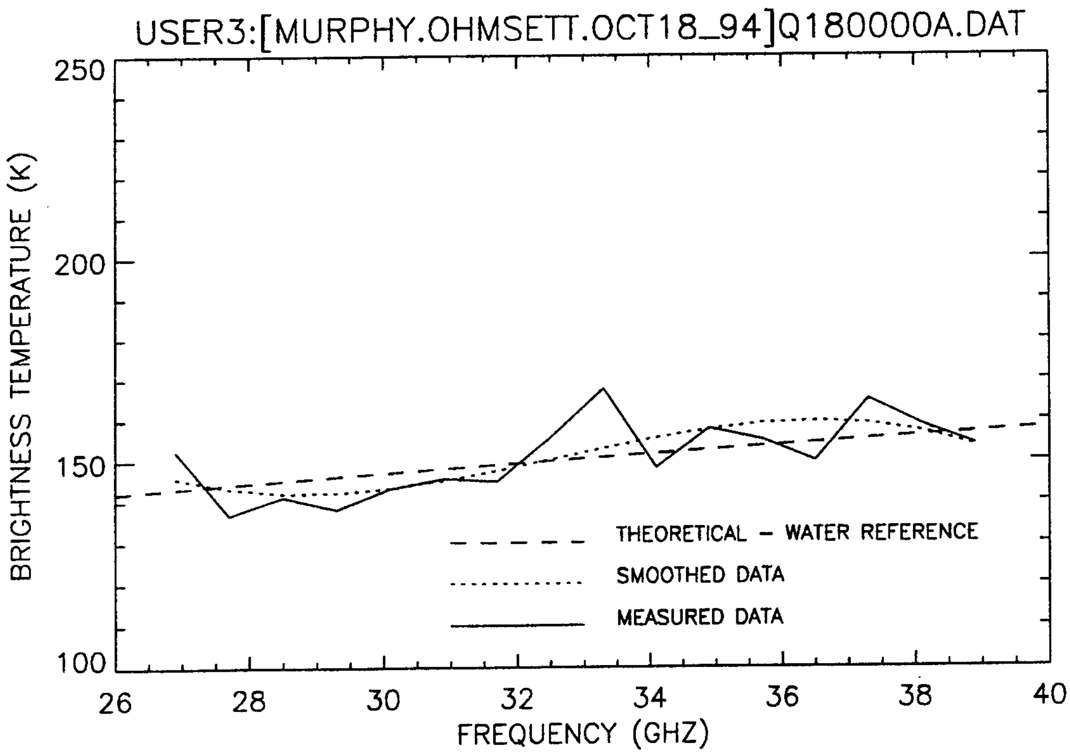

Figure E-120 T^B Versus Frequency Plot for Background Water, Chop Condition 2, 18 October 1994, Pass 1

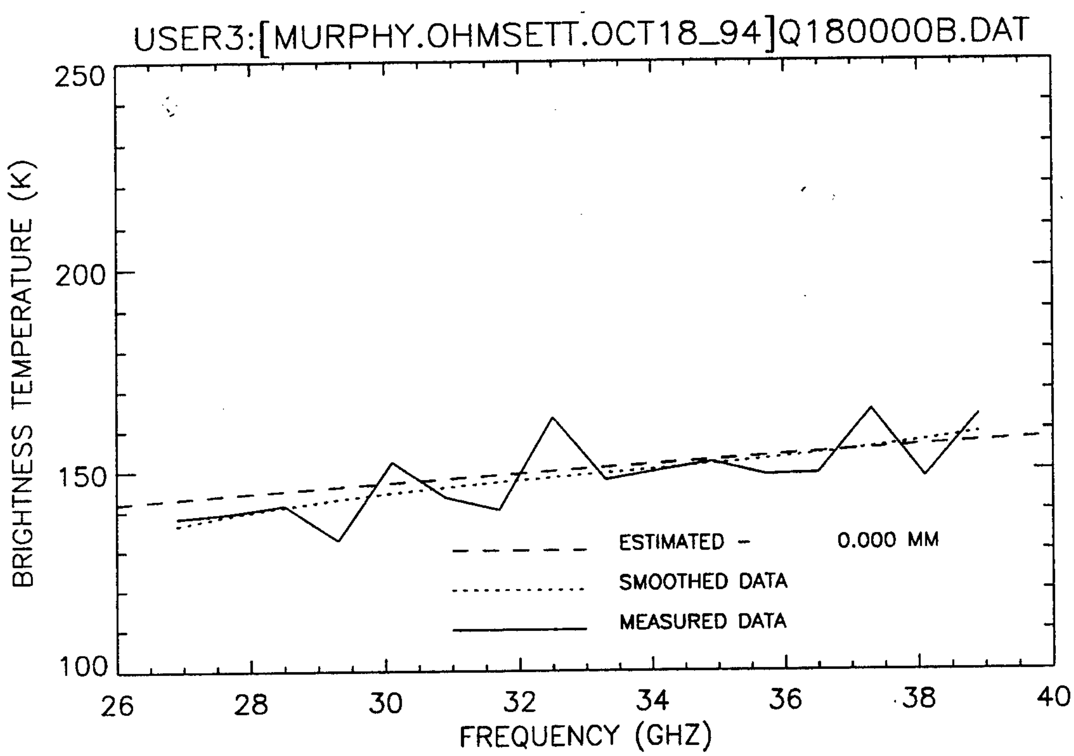

Figure E-121 T^B Versus Frequency Plot for Background Water, Chop Condition 2, 18 October 1994, Pass 2

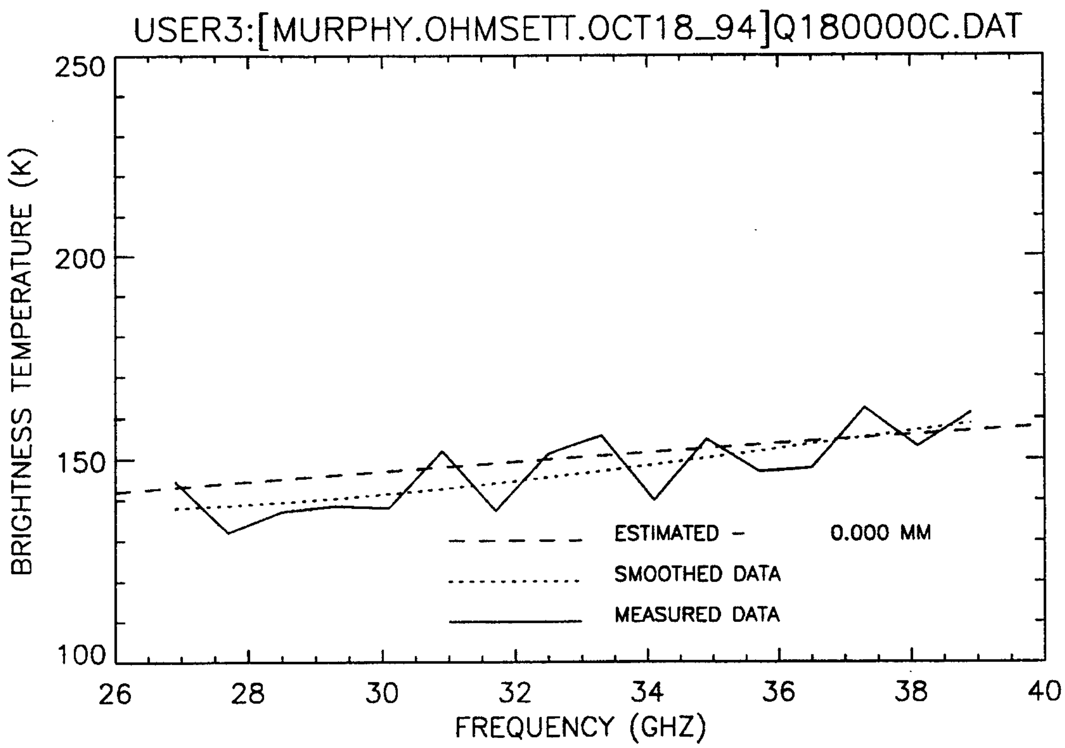

Figure E-122 T^B Versus Frequency Plot for Background Water, Chop Condition 2, 18 October 1994, Pass 3

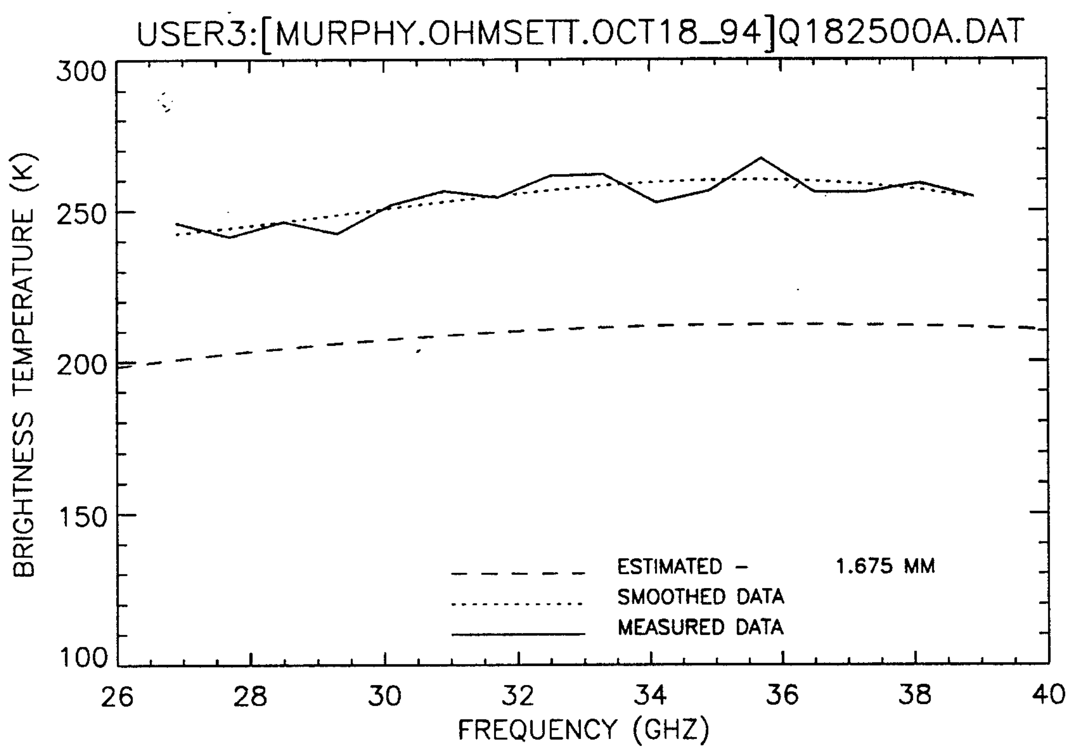

Figure E-123 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, Chop Condition 2, 18 October 1994, Pass 1

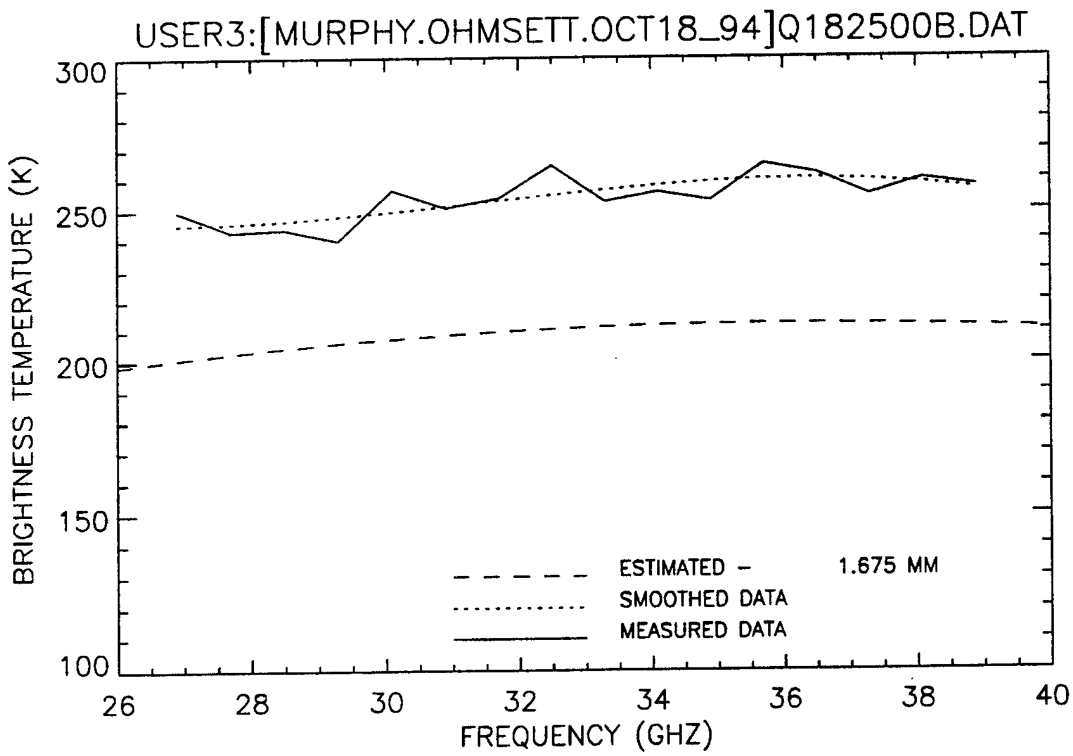

Figure E-124 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, Chop Condition 2, 18 October 1994, Pass 2

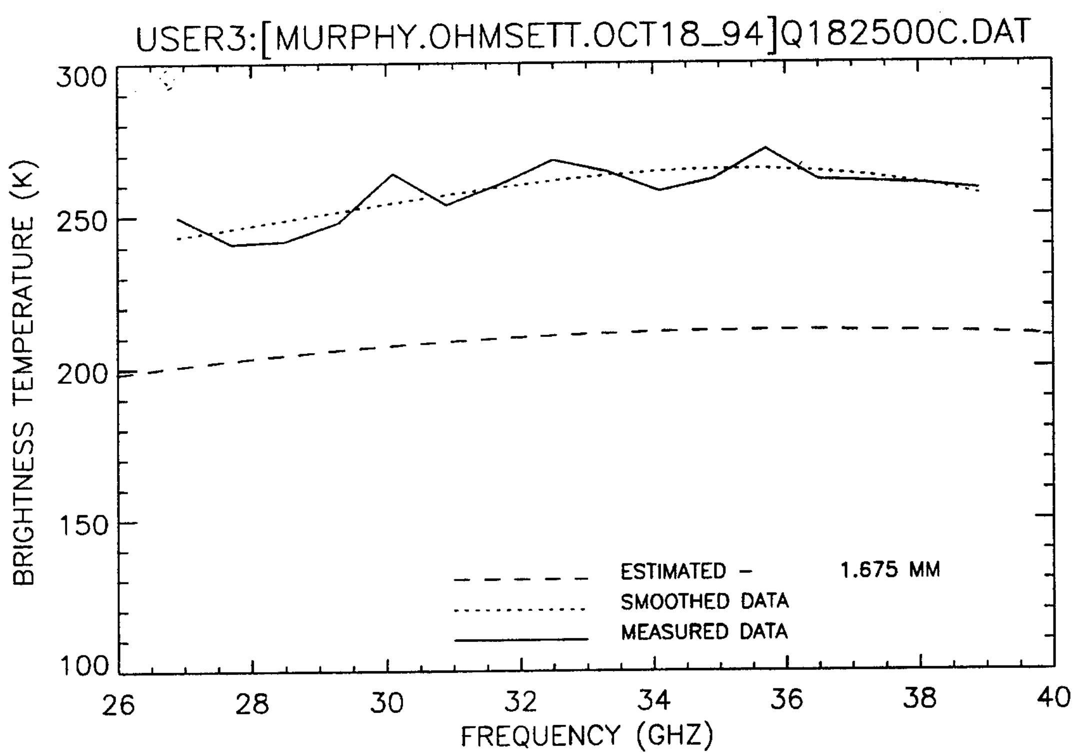

Figure E-125 T^B Versus Frequency Plot for 2.5 mm, 100% Coverage, Crude Oil, Chop Condition 2, 18 October 1994, Pass 3

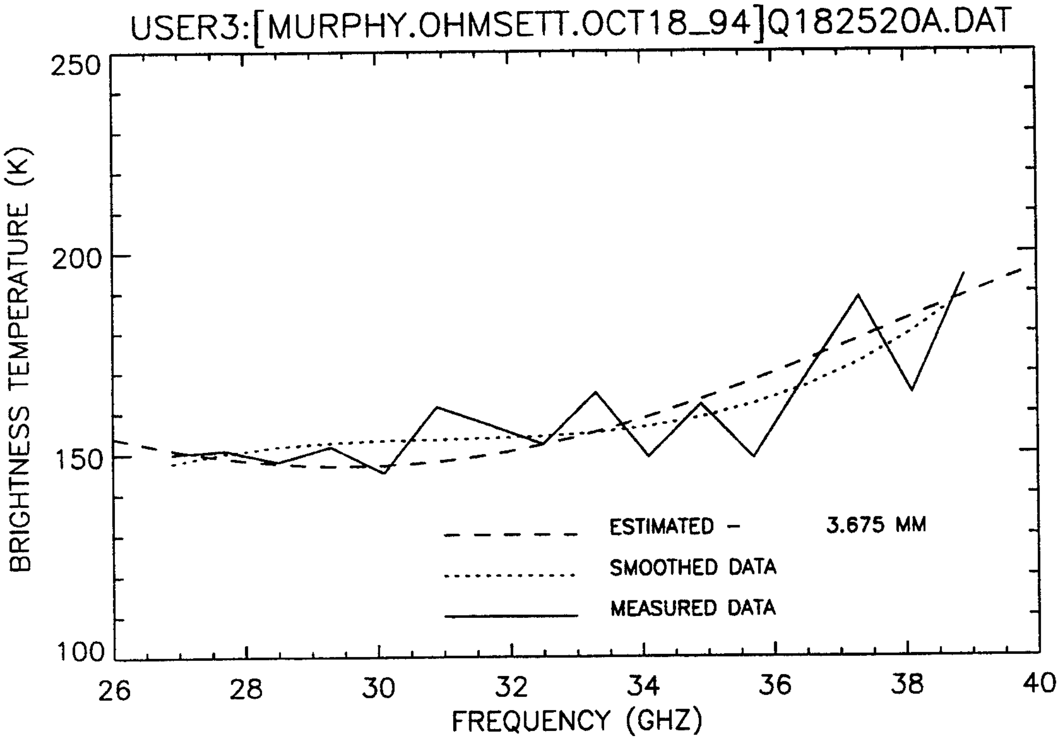

Figure E-126 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, Chop Condition 2, 18 October 1994, Pass 1

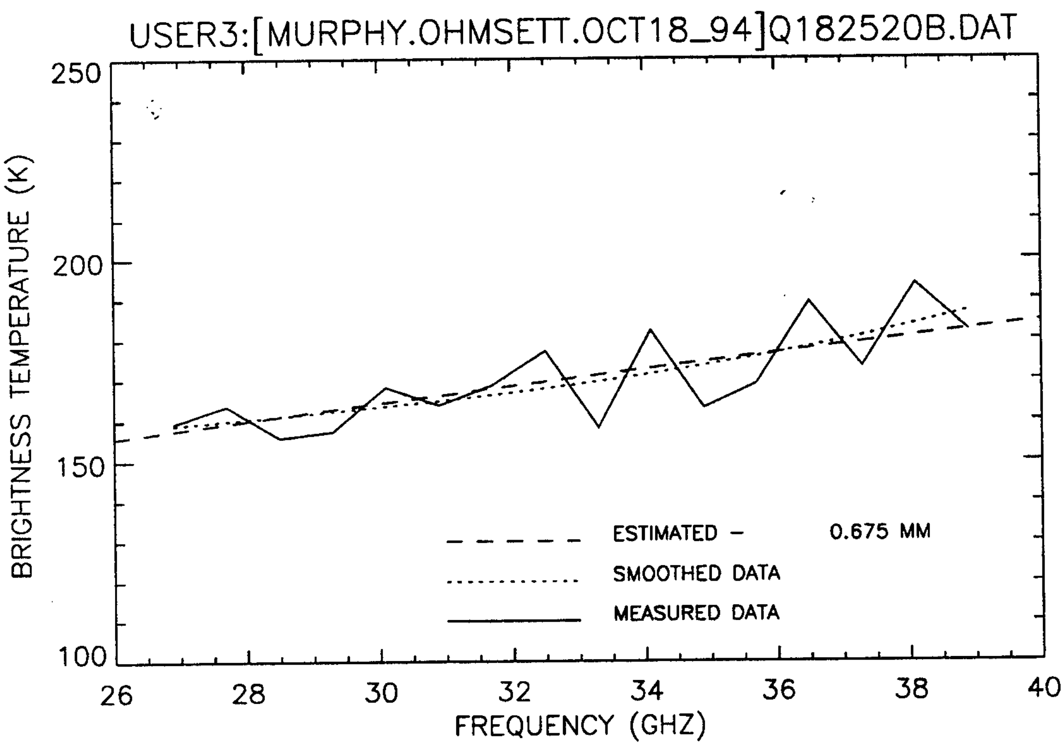

Figure E-127 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, Chop Condition 2, 18 October 1994, Pass 2

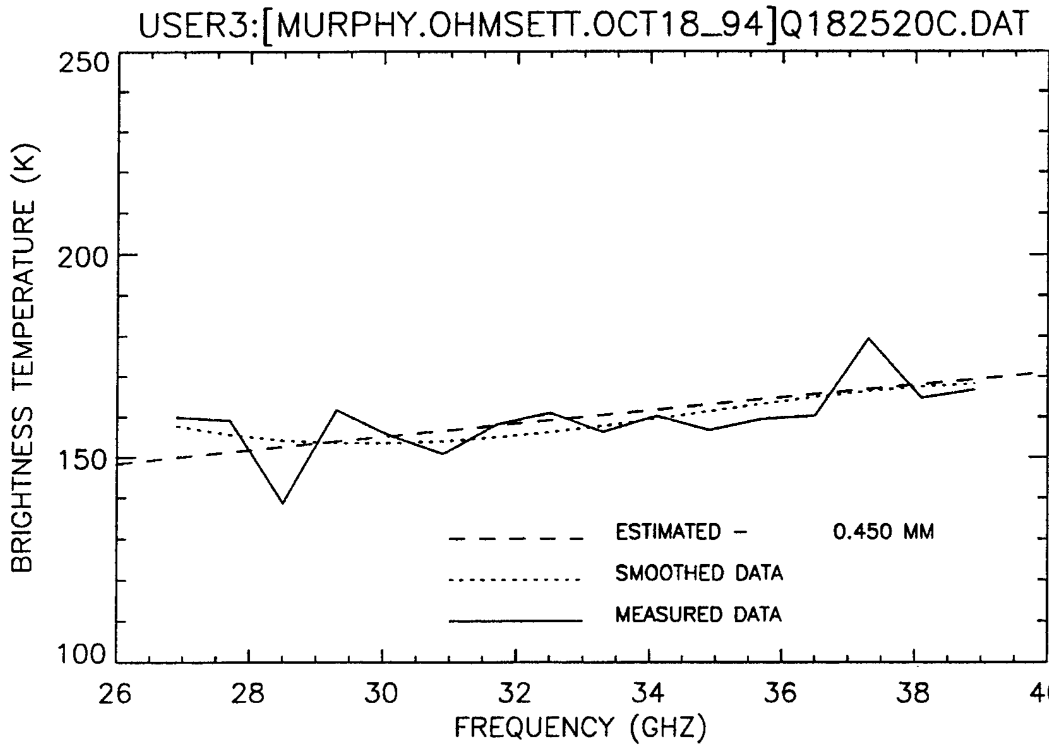

Figure E-128 T^B Versus Frequency Plot for 2.5 mm, 20% Coverage, Crude Oil, Chop Condition 2, 18 October 1994, Pass 3

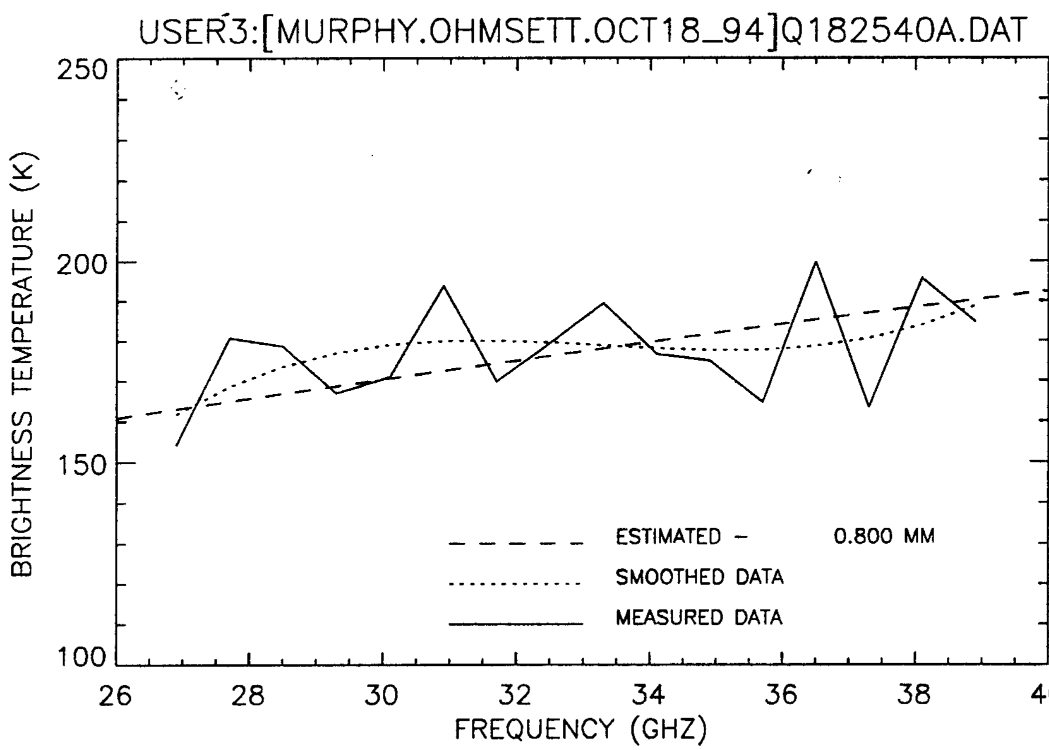

Figure E-129 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, Chop Condition 2, 18 October 1994, Pass 1

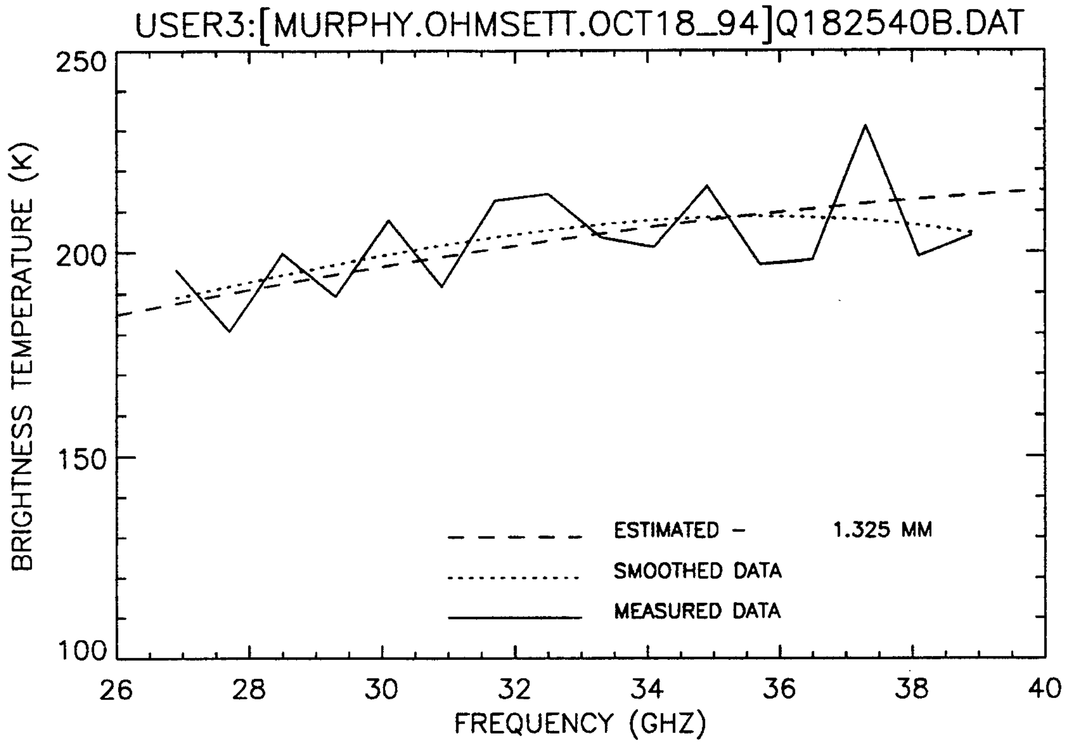

Figure E-130 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, Chop Condition 2, 18 October 1994, Pass 2

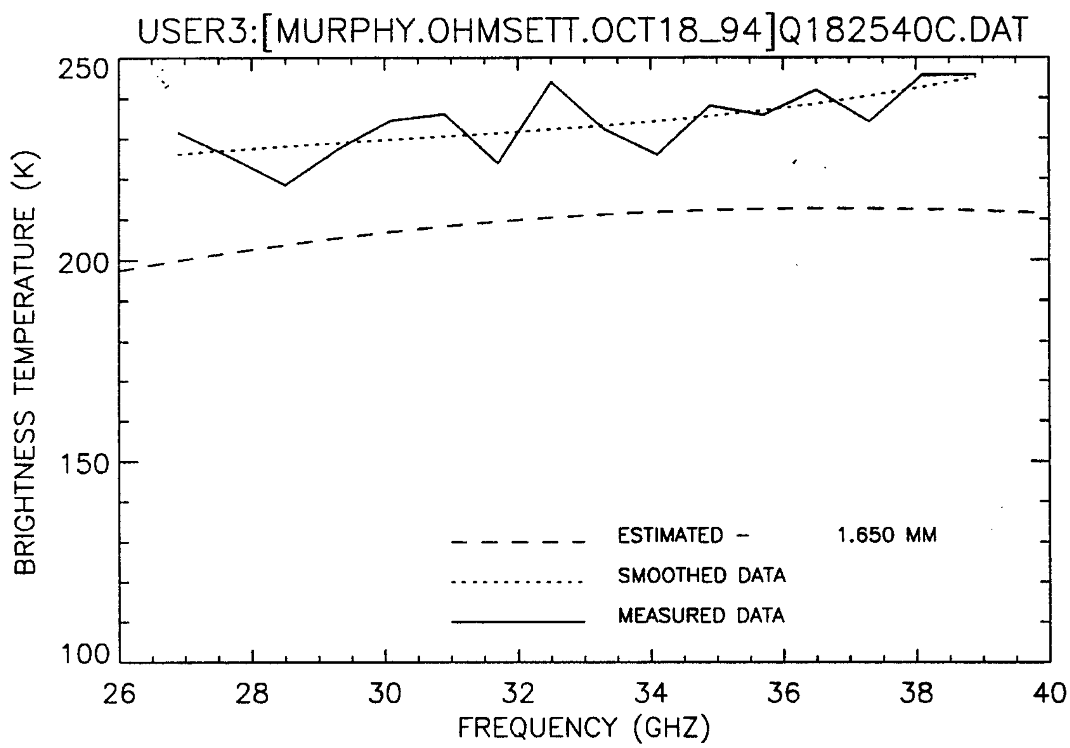

Figure E-131 T^B Versus Frequency Plot for 2.5 mm, 40% Coverage, Crude Oil, Chop Condition 2, 18 October 1994, Pass 3

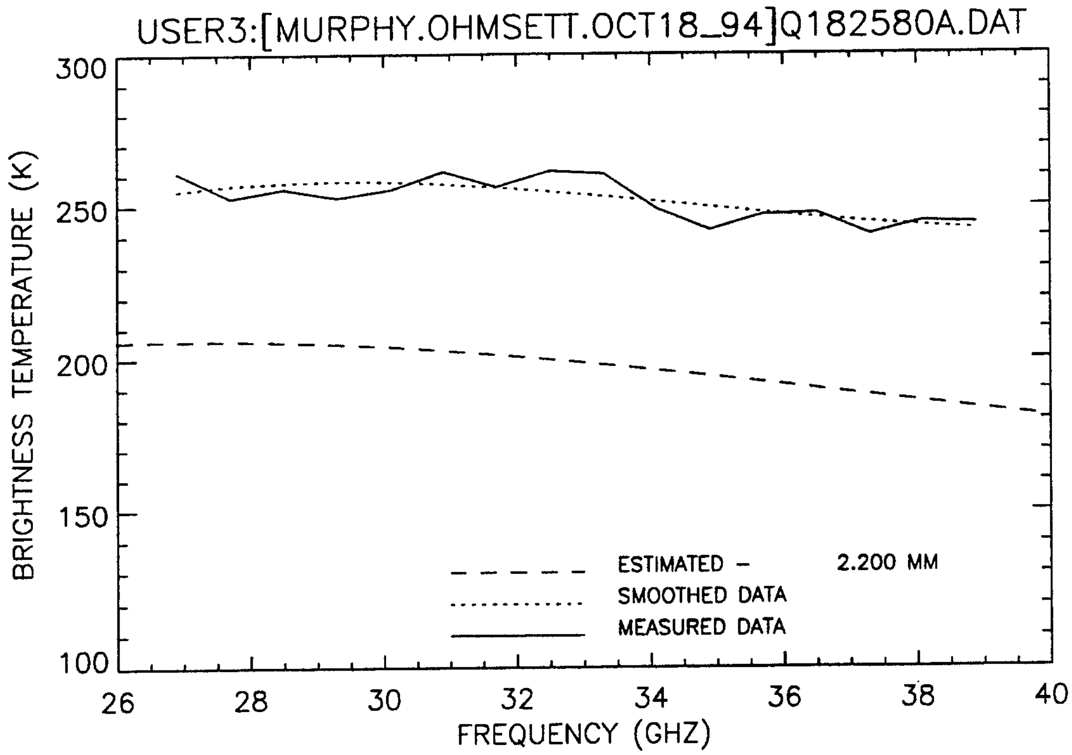

Figure E-132 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, Chop Condition 2, 18 October 1994, Pass 1

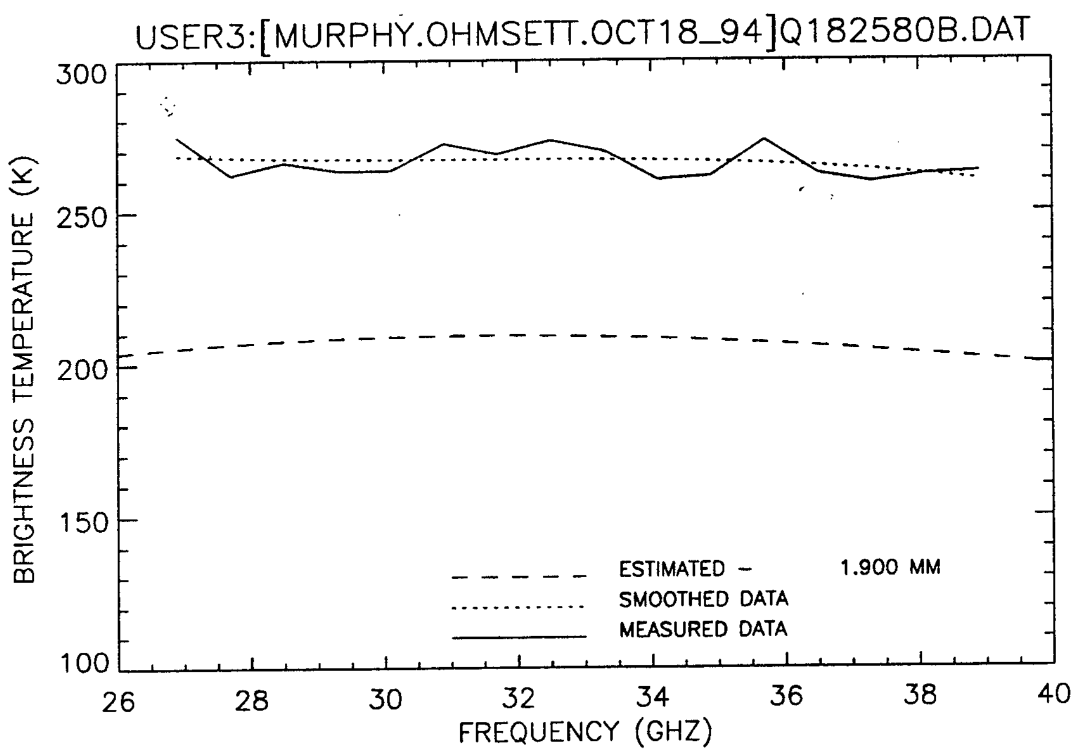

Figure E-133 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, Chop Condition 2, 18 October 1994, Pass 2

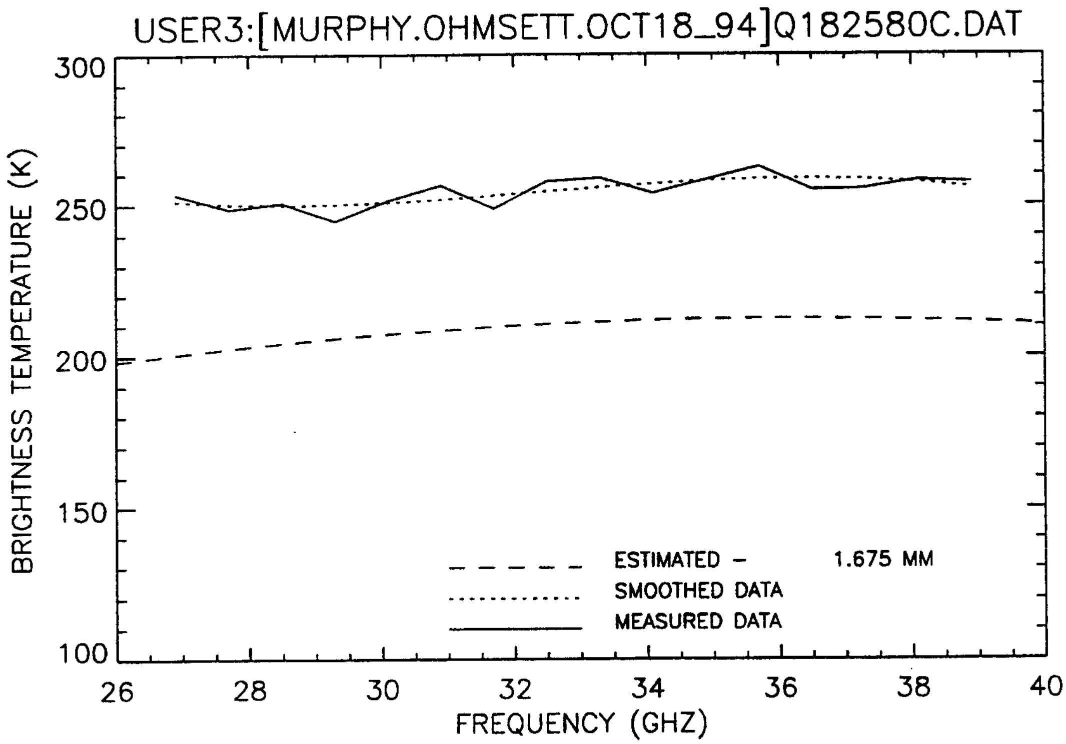

Figure E-134 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, Chop Condition 2, 18 October 1994, Pass 3

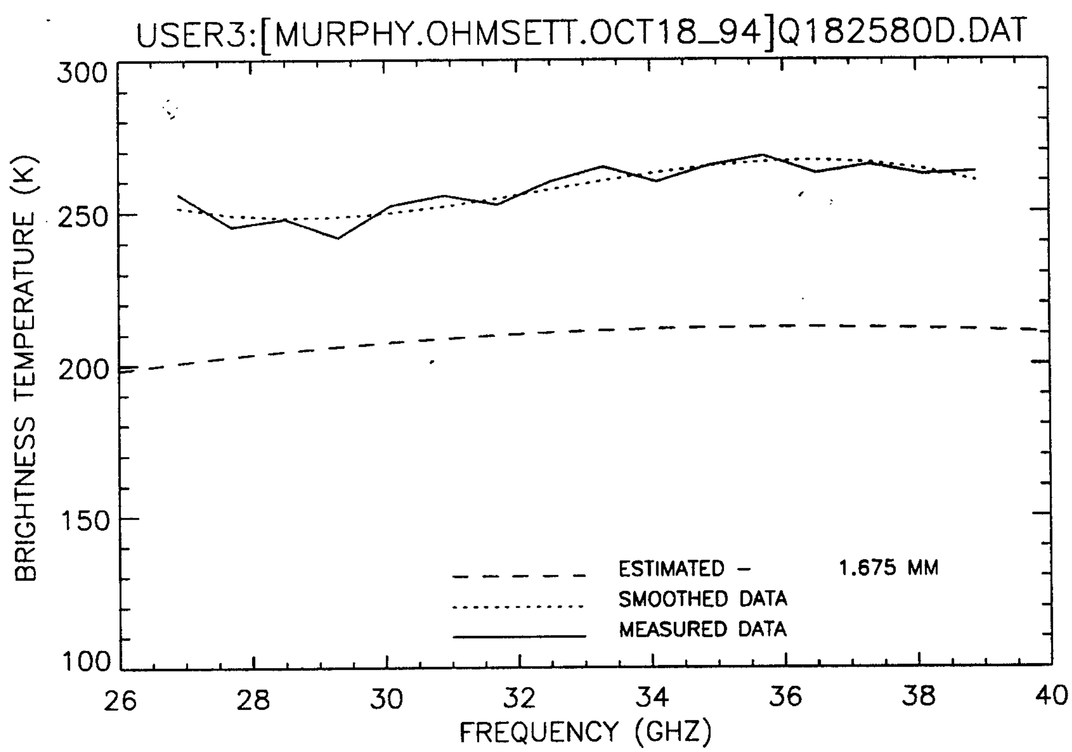

Figure E-135 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, Chop Condition 2, 18 October 1994, Pass 4

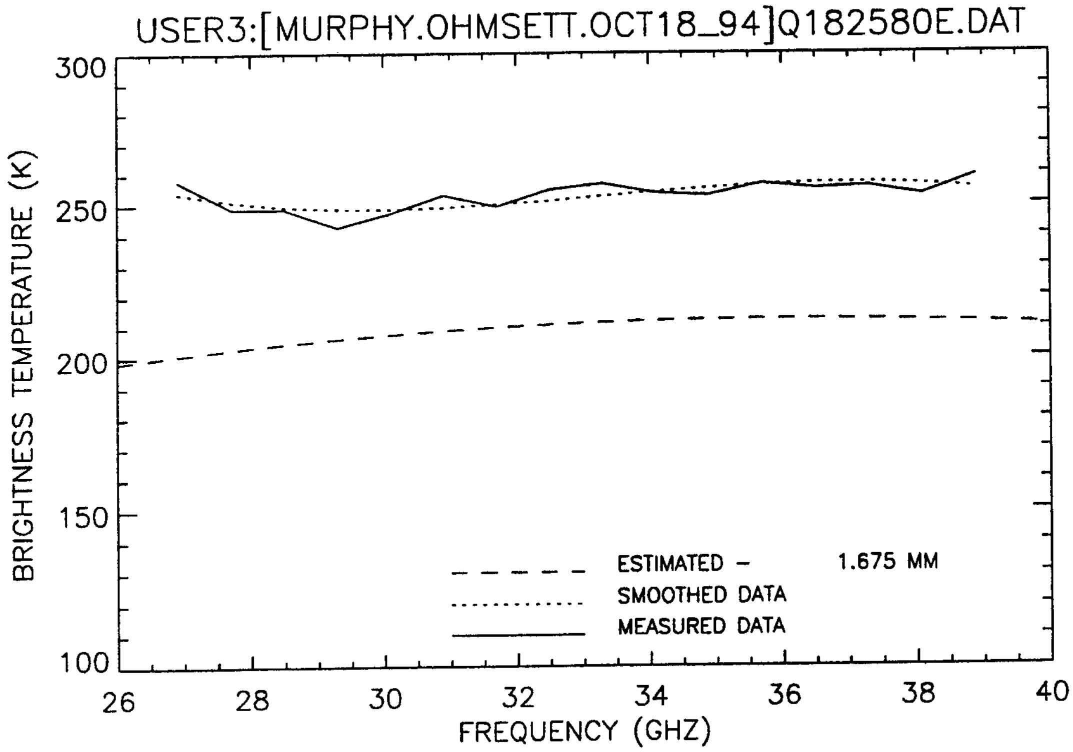

Figure E-136 T^B Versus Frequency Plot for 2.5 mm, 80% Coverage, Crude Oil, Chop Condition 2, 18 October 1994, Pass 5

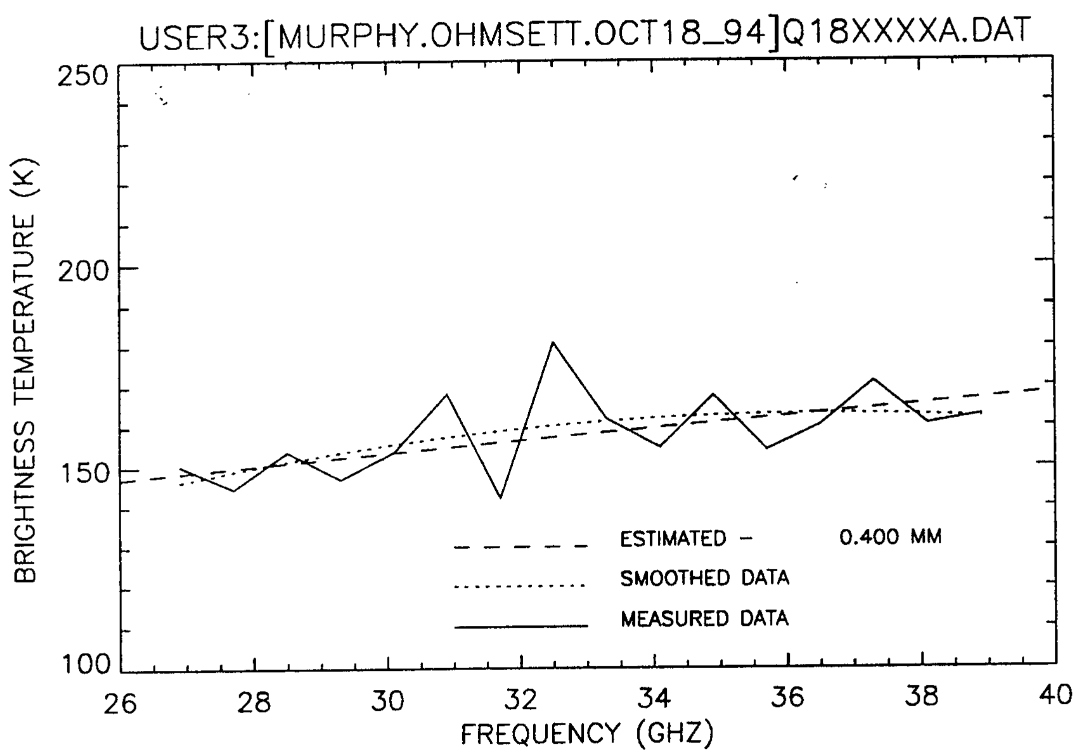

Figure E-137 T^B Versus Frequency Plot for Tar Balls Outside of Containment, Crude Oil, Chop Condition 2, 18 October 1994, Pass 1

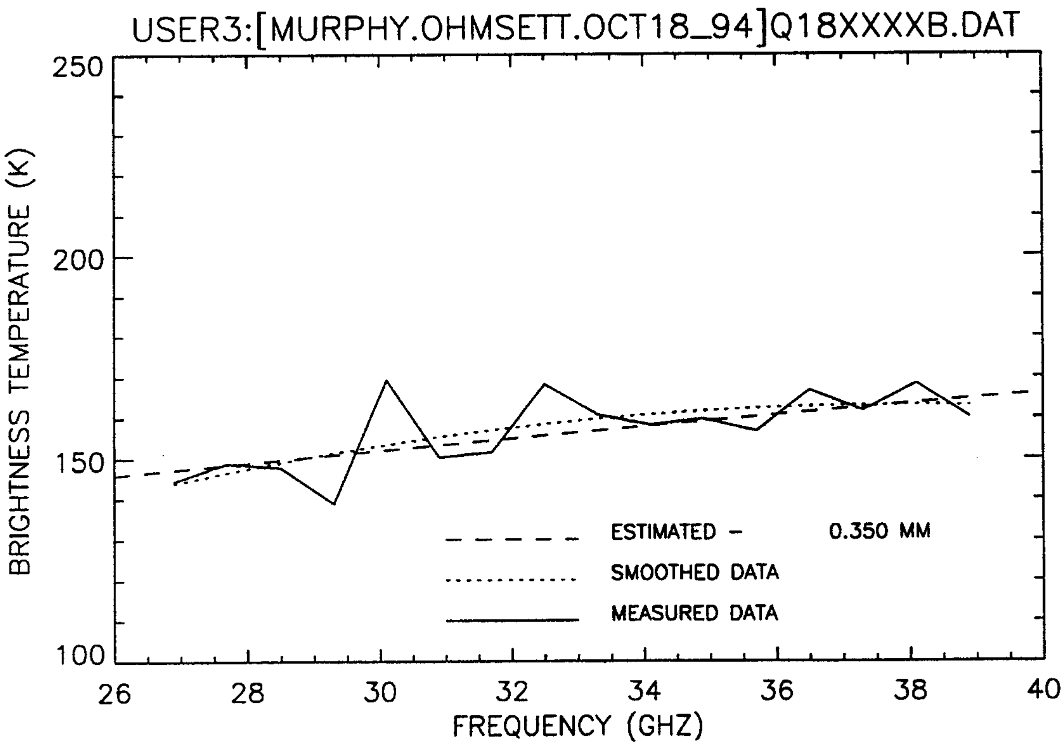

Figure E-138 T^B Versus Frequency Plot for Tar Balls Outside of Containment, Crude Oil, Chop Condition 2, 18 October 1994, Pass 2

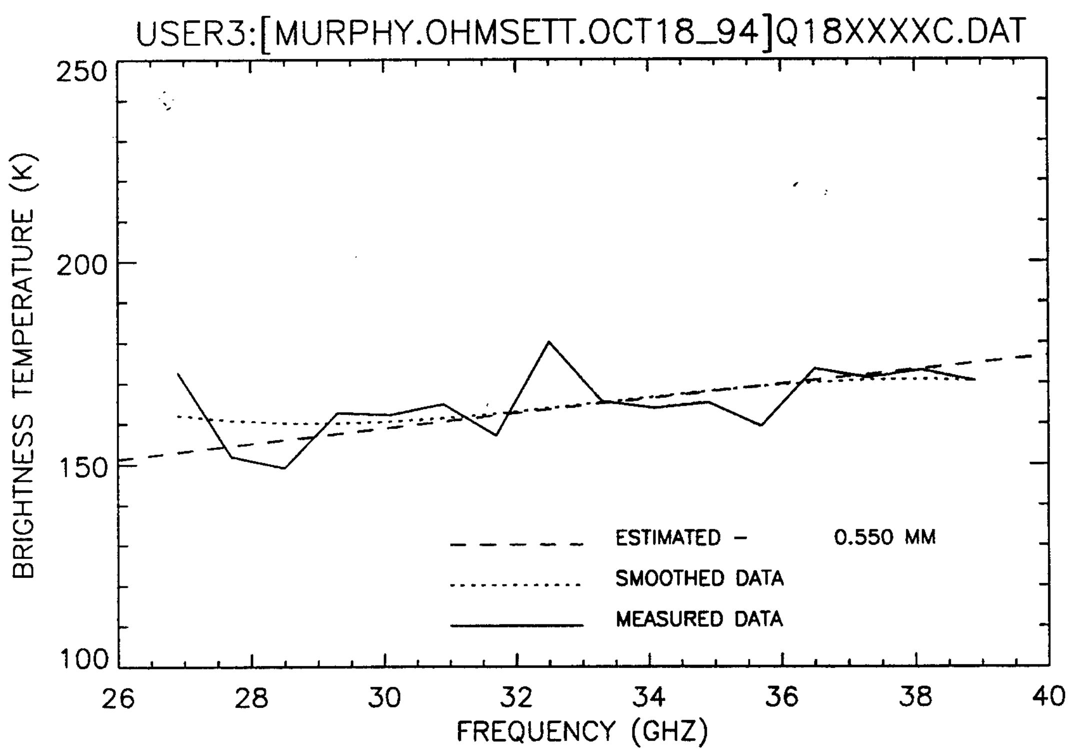

Figure E-139 T^B Versus Frequency Plot for Tar Balls Outside of Containment, Crude Oil, Chop Condition 2, 18 October 1994, Pass 3

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APPENDIX F

BRIGHTNESS TEMPERATURE VERSUS FREQUENCY PLOTS FROM OHMSETT TYPE 3 OIL (EMULSION) TESTS

The frequency scanning radiometer was set up at the OHMSETT facility on the main equipment bridge with the oil pools in the radiometer antenna field of view. Tests using type 3 oil were conducted on 14 October 1994.

The file naming convention used for data files was wwppttx.DAT, where ww is a letter identifier for the wave condition (EM = calm condition, EW = chop 2), pp is the percent of water by volume in the water/oil emulsion, tt is the expected oil pool target thickness in tenths of a millimeter, and x is the pass identifier. Thus EM4020C.DAT was the third pass collected on 14 October 1994 under calm wave conditions, with an anticipated oil target thickness of 2.0 mm of 40% water 60% oil emulsion.

The plots shown in this appendix, figures F-1 through F-34, are radiometric brightness temperature (T^B), expressed in Kelvin (K), as measured by the FSR, versus the measurement frequency in GHz. Under the current FSR software configuration, sixteen equally spaced points between 26.5 GHz and 40.0 GHz are sampled, with each sample period somewhat less than one second. These sixteen points are plotted as 'measured' points. For each data set, the oil thickness estimation algorithm, described in Chapter 4, is used to estimate an oil film thickness. This algorithm derived estimate is displayed with the smoothed curve and the declared result plotted over the actual measured points. The data analyst can then either choose to accept the algorithm estimate, or manually select a curve that may be a better fit to the measured data. Comments are provided for each measurement concerning the fit of the algorithm estimate and the analyst's choice for each curve's best fit.

The plots in this appendix are arranged by test session. At the beginning of each test session data set, comments are provided for each measurement concerning the fit of the algorithm estimate and the analyst's choice for each curve's best fit.

When viewing the plots, it is important to understand that the figure titles cite only the target oil thickness value within the test pool being viewed. As described in chapter 3, the actual thickness of oil being viewed by the FSR at any given moment could vary substantially from this target value.

Emulsions tended to form cohesive patches and did not tend to spread evenly over the containment area. Thus, measurements were collected over areas containing the oil patch but the oil did not fully fill the antenna footprint.

EM0000A - This curve is a fair-to-good match to the algorithm estimate of 0.000 mm. Note that the measured T^B exhibits some fluctuation about the estimated water reference curve. The fluctuation may be due to equipment warm-up effects or possibly a poor calibration.

EM0000B - This is the water reference that was chosen for this set of measurements. Note that the measured T^B shows the same fluctuation about the theoretical water reference curve as the first measurement.

EM0000C - This curve is a fair-to-good match to the algorithm estimate of 0.025 mm. Note that this curve exhibits the same type of T^B fluctuation as the first two curves.

This set of three measurements was collected over a single large patch of oil in the 20%-water/80%-oil emulsion, 1.0 mm intended thickness oil target pool. Oil covered approximately 25% of the antenna footprint.

EM2010A - This curve is a good match to the algorithm estimate of 0.425 mm. This curve is somewhat flatter (less slope) than would be expected; nonetheless, it is still a good match to the estimate.

EM2010B - This curve is a fair match to the algorithm estimate of 0.375 mm; however, an estimate of 0.450 mm (plotted) is a better match.

EM2010C - This curve is an excellent match to the algorithm estimate of 0.150 mm. This measurement was collected over the same patch as the previous two measurements; it is not understood why the results appear different.

The OHMSETT main bridge was moved to a new measurement location within the same oil pool. The next two measurements were taken over an area with small patches of oil that totaled approximately 5 - 10% antenna beam fill.

EM2010D - This curve is an excellent match to the algorithm estimate of 0.200 mm.

EM2010E - This curve is an excellent match to the algorithm estimate of 0.225 mm.

The main bridge was set over the pool containing an intended 2.0 mm thickness of 20%-water/80%-oil emulsion with an actual antenna beam fill of approximately 50%. Both of the following measurements were collected over the same oil patch, although the FSR may have been repositioned to obtain a somewhat larger antenna beam fill between the two measurements.

EM2020A - This curve is a good match to the algorithm estimate of 0.425 mm.

EM2020B - This curve is a fair-to-good match to the algorithm estimate of 0.800 mm.

The main bridge was moved to a different area of the pool to obtain a higher antenna beam fill of approximately 90%. Note that the estimated thicknesses are nearly twice the previous estimates. Although the main bridge was not moved, the FSR was repositioned between the EM2020C and EM2020D measurements.

EM2020C - This curve is a good match to the algorithm estimate of 1.375 mm.

EM2020D - This curve is a good match to the algorithm estimate of 1.600 mm.

The main bridge was set over a target pool with an intended 1.0 mm thickness of 40%-water/60%-oil emulsion. The following measurements were made with approximately 60 - 65% beam fill.

EM4010A - This curve is a poor match to the algorithm estimate of 1.075 mm. The curve seems to exhibit a shape more characteristic of a 1.6 mm estimate; however, the overall T^B seems too low. The result is inconclusive.

EM4010B - This curve is a poor match to the algorithm estimate of 1.125 mm. The curve seems to exhibit a shape more characteristic of a 1.6 - 1.7 mm estimate (1.7 mm plotted); however, the overall T^B seems too low. The result is inconclusive.

EM4010C - This curve is a poor match to the algorithm estimate of 1.175 mm. The curve seems to exhibit a shape more characteristic of a 1.6 - 1.7 mm estimate; however, the overall T^B seems too low. The result is inconclusive.

The FSR antenna was moved to measure a different location in the same oil pool where the antenna beam fill was approximately 50%.

EM4010D - This curve is a poor match to the algorithm estimate of 1.050 mm. The curve seems to exhibit a shape more characteristic of a 1.6 - 1.7 mm estimate; however, the overall T^B seems too low. The result is inconclusive.

The FSR antenna was moved to measure a different location in the same oil pool where the antenna beam fill was less than 50%.

EM4010E - This curve is a fair-to-good match to the algorithm estimate of 0.650 mm.

The main bridge was positioned over the target pool with an intended 2.0 mm thickness of 40%-water/60%-oil emulsion. The beam fill is estimated to be approximately 50%.

EM4020A - This curve is a fair-to-good match to the algorithm estimate of 1.700 mm, although the overall T^B is slightly less than expected.

EM4020B - This curve is a poor match to the algorithm estimate of 1.150 mm. The curve seems to exhibit a shape more characteristic of a 1.6 - 1.7 mm estimate; however, the overall T^B seems somewhat low. The result is inconclusive.

EM4020C - This curve is a poor match to the algorithm estimate of 1.175 mm. The curve seems to exhibit a shape more characteristic of a 1.6 - 1.7 mm

estimate; however, the overall T^B seems somewhat low. The result is inconclusive.

The FSR antenna was repositioned to measure a different patch of emulsion. The antenna beam fill is estimated to be approximately 50%.

EM4020D - This curve is a poor match to the algorithm estimate of 2.025 mm. The curve seems to exhibit a shape more characteristic of a 1.8 mm estimate; however, the overall T^B is somewhat low.

EM4020E - This curve is a poor match to the algorithm estimate of 1.975 mm. The curve seems to exhibit a shape more characteristic of a 1.7 mm estimate; however, the overall T^B is somewhat low.

Overall, the EM4020A - E data had a consistent shape characteristic, namely, a flat slope. The slight variations observed in the mean T^B may be caused by small differences in the antenna beam fill.

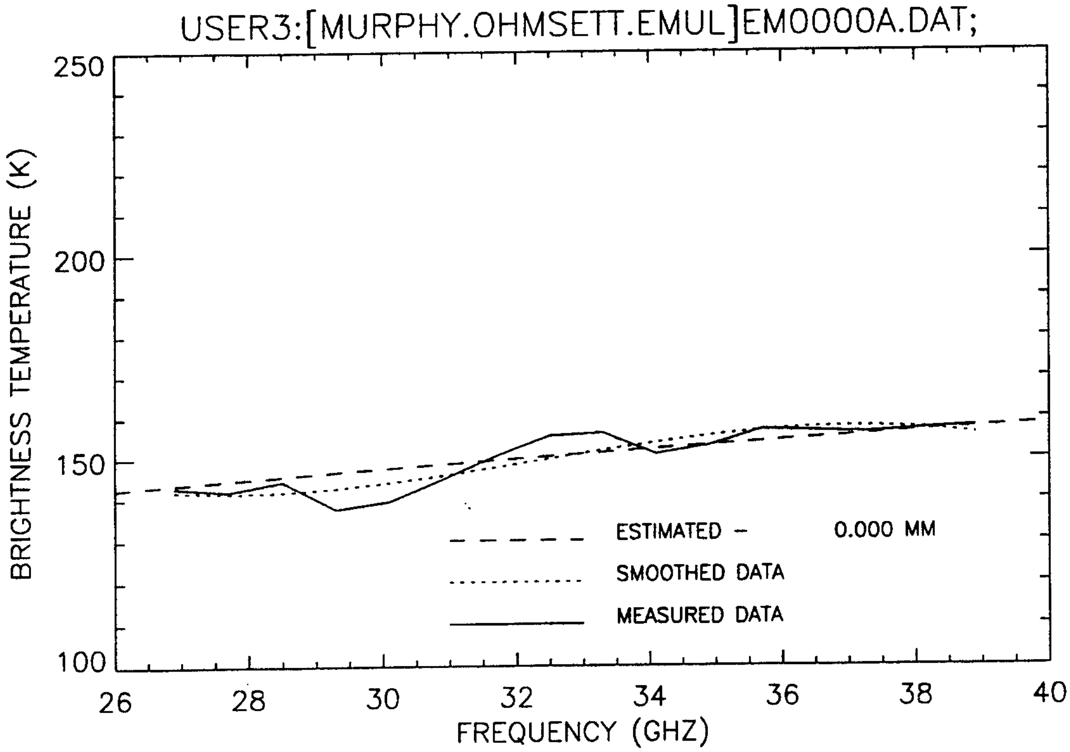

Figure F-1 T^B Versus Frequency Plot for Background Water, 14 October 1994, Pass 1

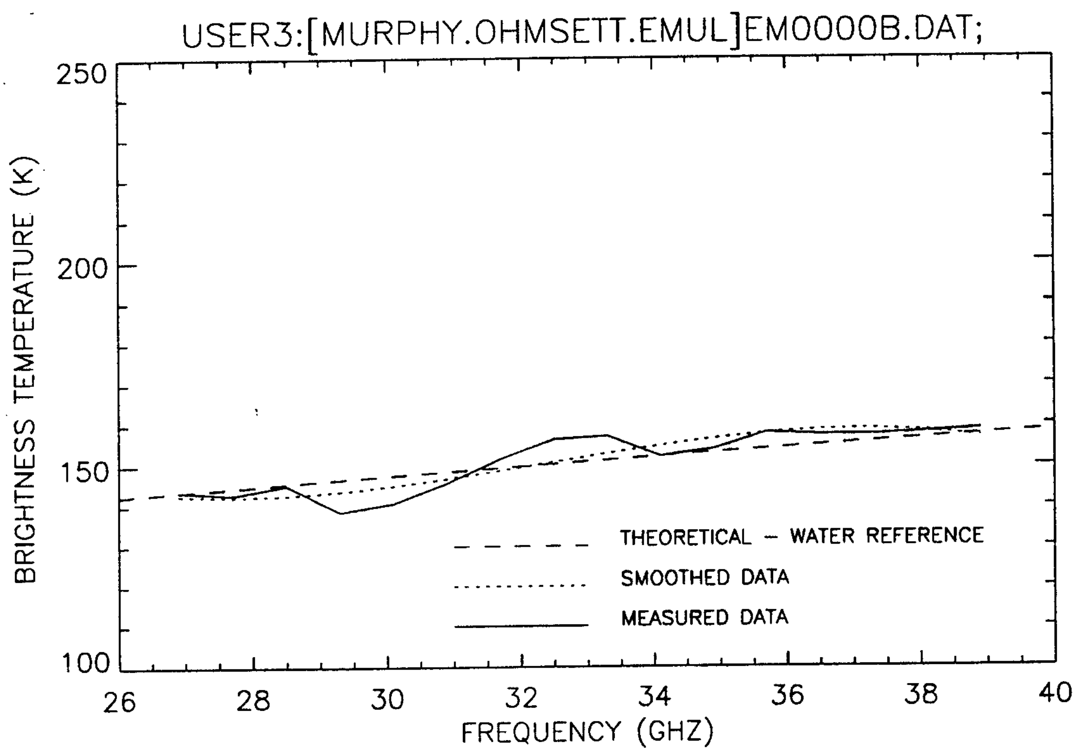

Figure F-2 T^B Versus Frequency Plot for Background Water, 14 October 1994, Pass 2

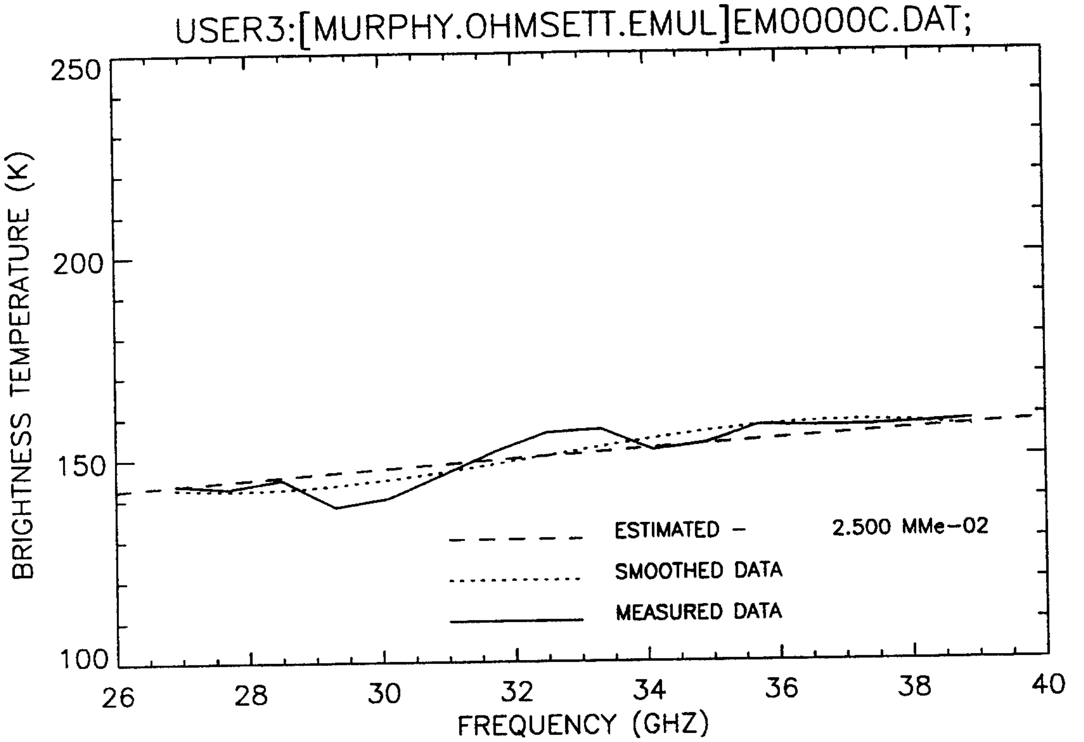

Figure F-3 T^B Versus Frequency Plot for Background Water, 14 October 1994, Pass 3

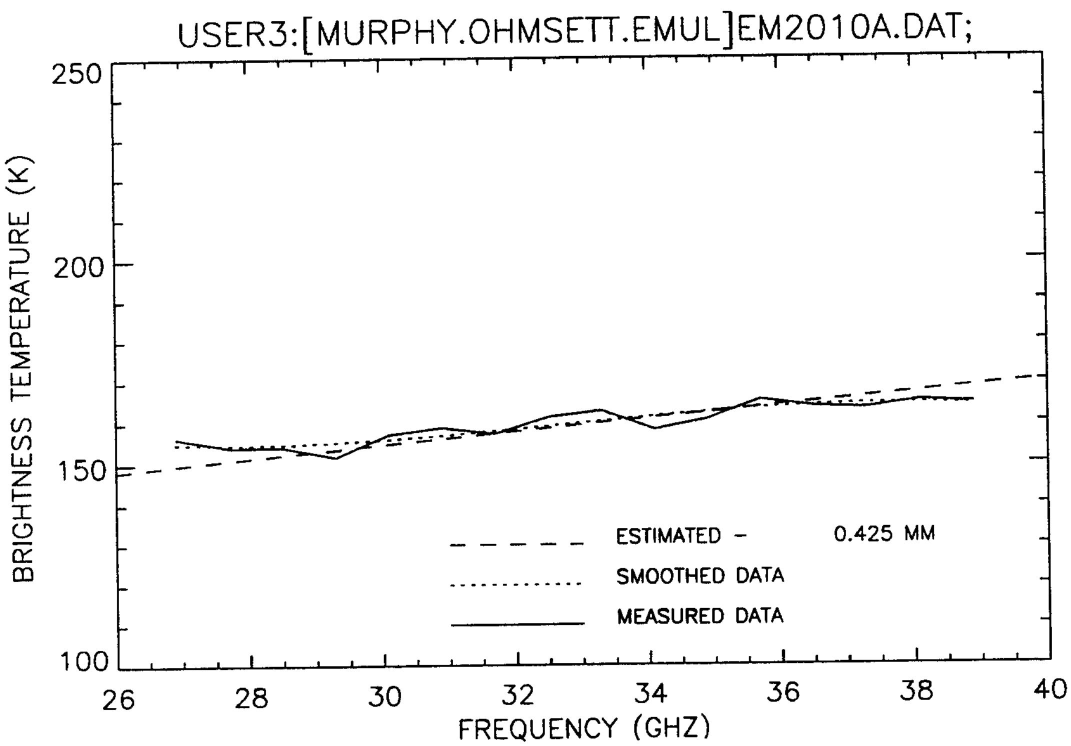

Figure F-4 T^B Versus Frequency Plot for a 1.0 mm Volume of 20% Water-80% Oil Emulsion, 14 October 1994, Pass 1

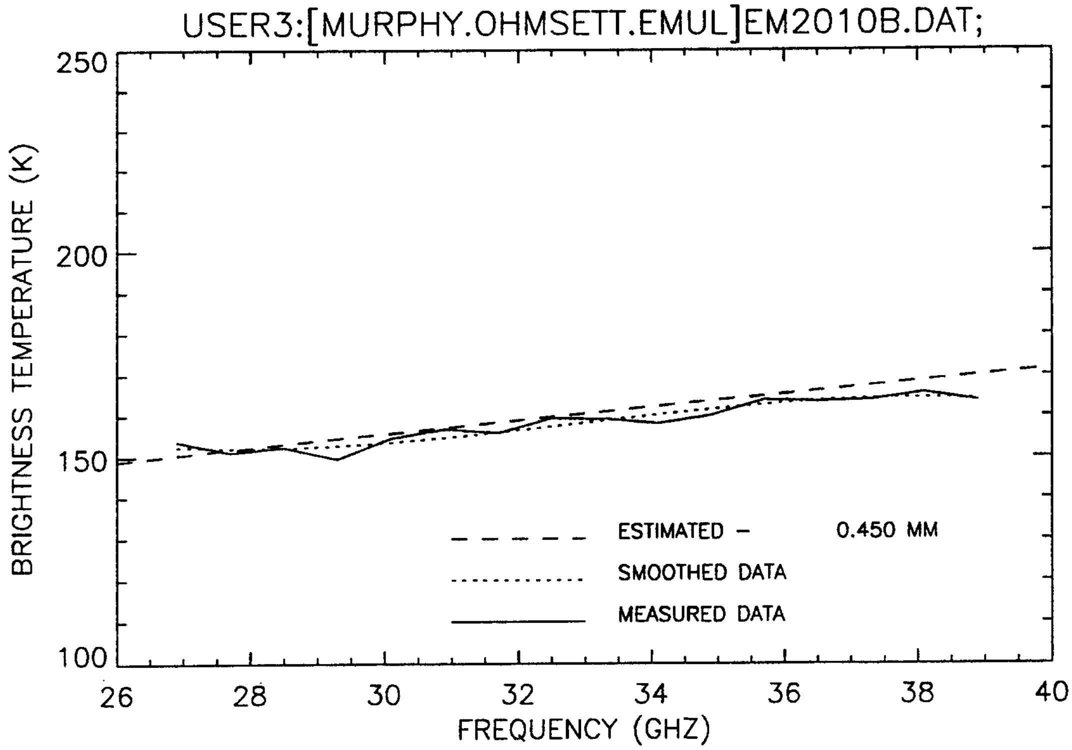

Figure F-5 T^B Versus Frequency Plot for a 1.0 mm Volume of 20% Water-80% Oil Emulsion, 14 October 1994, Pass 2

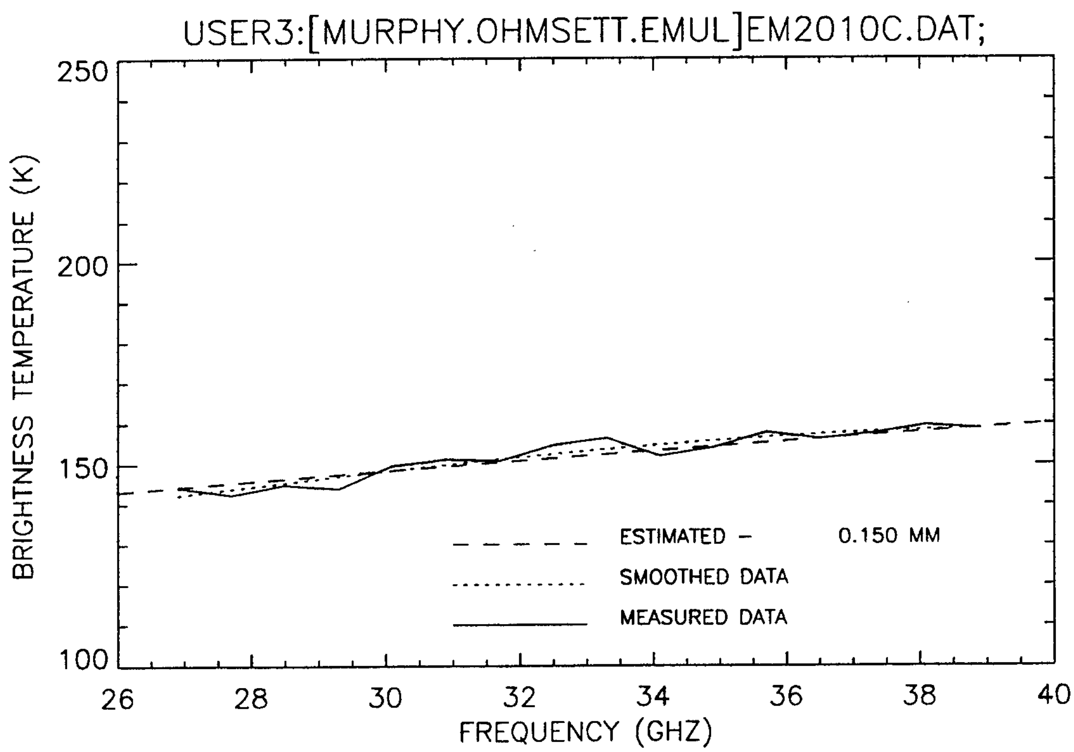

Figure F-6 T^B Versus Frequency Plot for a 1.0 mm Volume of 20% Water-80% Oil Emulsion, 14 October 1994, Pass 3

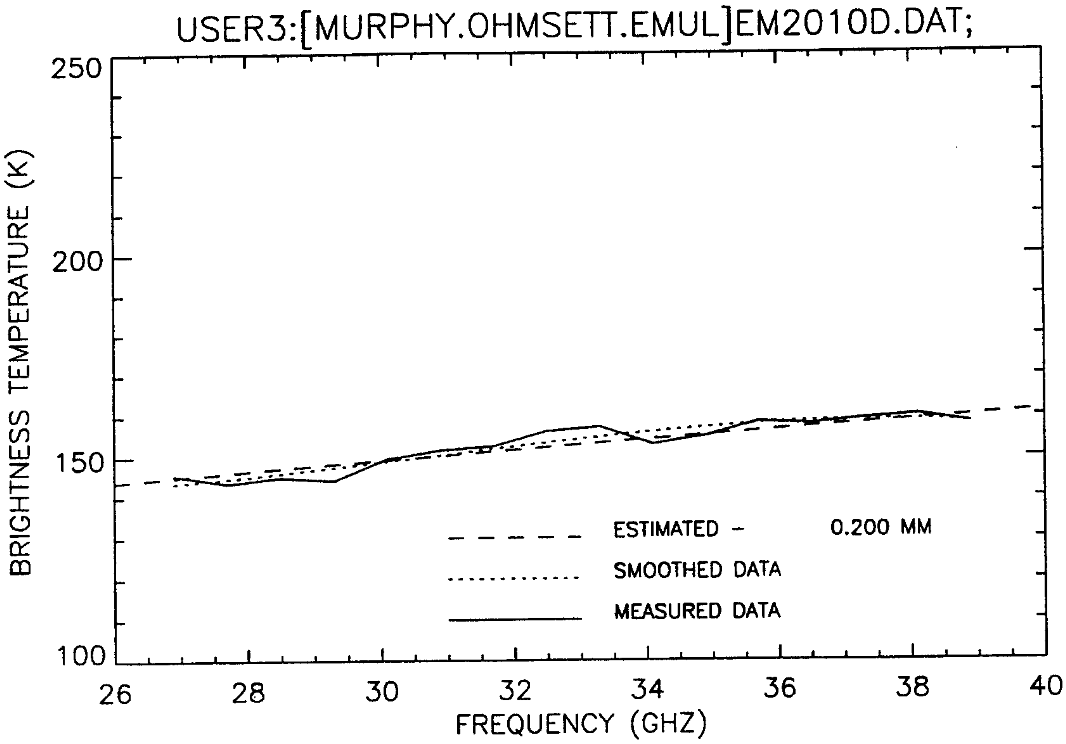

Figure F-7 T^B Versus Frequency Plot for a 1.0 mm Volume of 20% Water-80% Oil Emulsion, 14 October 1994, Pass 4

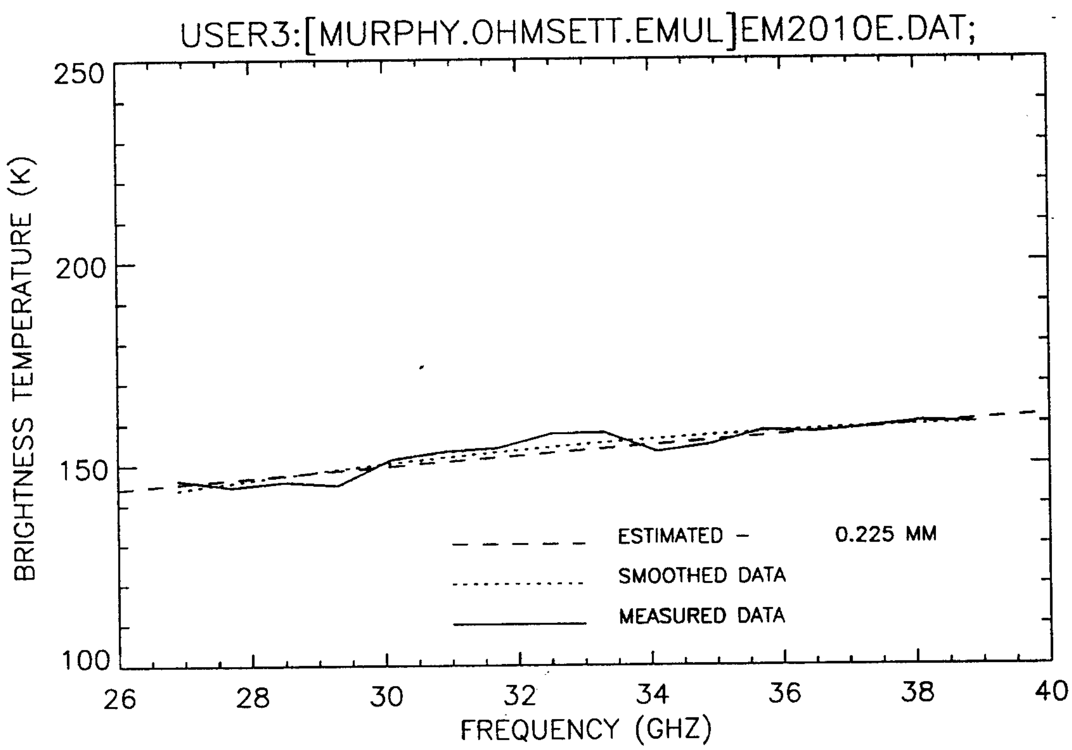

Figure F-8 T^B Versus Frequency Plot for a 1.0 mm Volume of 20% Water-80% Oil Emulsion, 14 October 1994, Pass 5

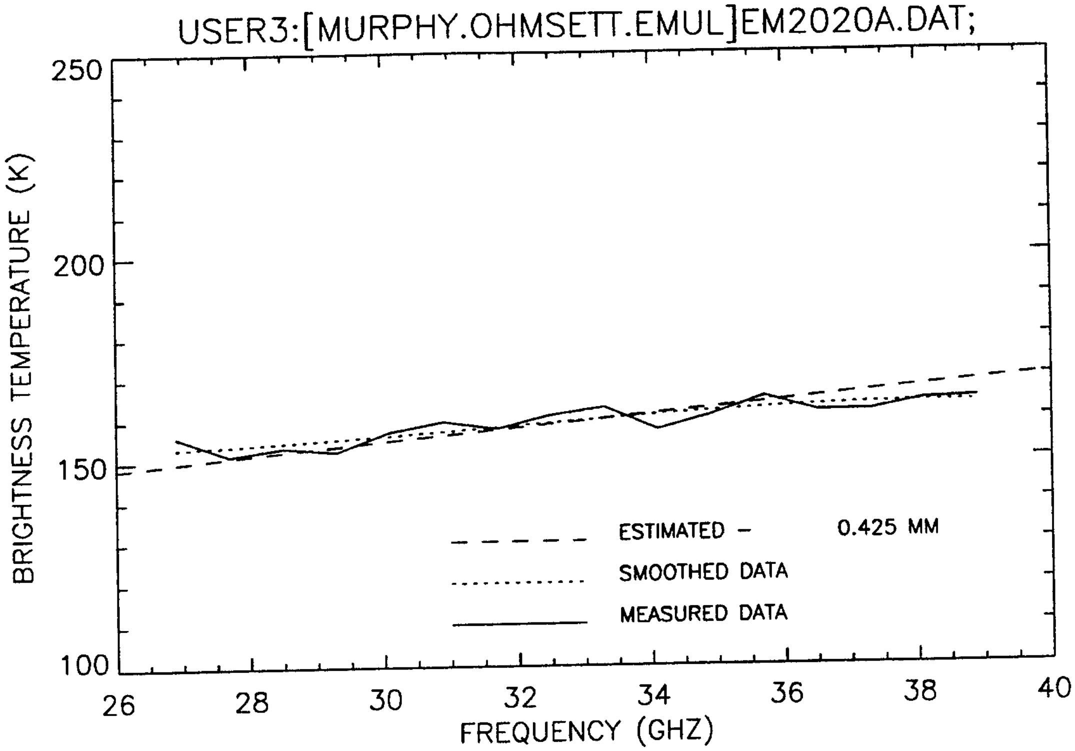

Figure F-9 T^B Versus Frequency Plot for a 2.0 mm Volume of 20% Water-80% Oil Emulsion, 14 October 1994, Pass 1

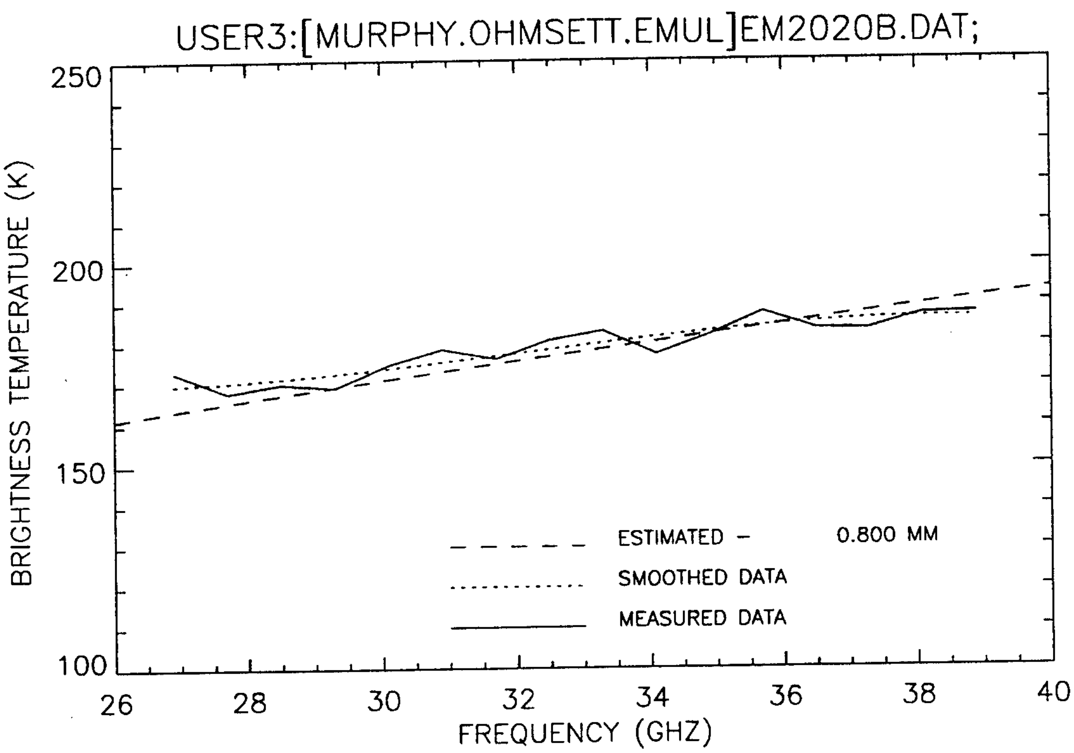

Figure F-10 T^B Versus Frequency Plot for a 2.0 mm Volume of 20% Water-80% Oil Emulsion, 14 October 1994, Pass 2

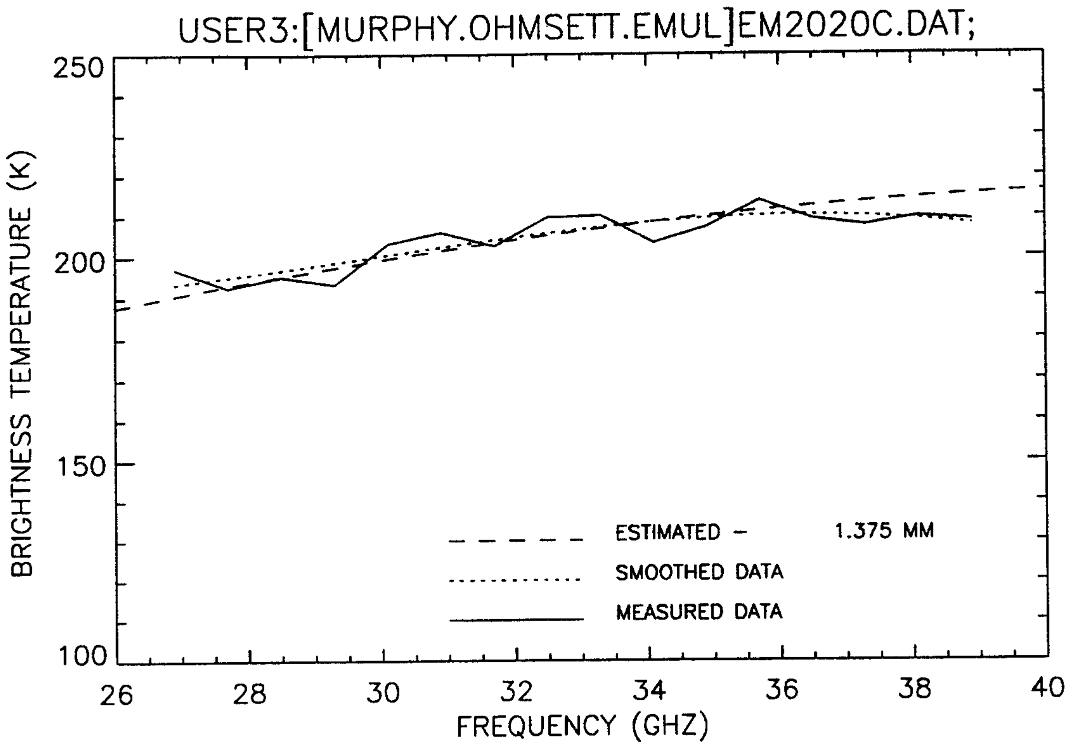

Figure F-11 T^B Versus Frequency Plot for a 2.0 mm Volume of 20% Water-80% Oil Emulsion, 14 October 1994, Pass 3

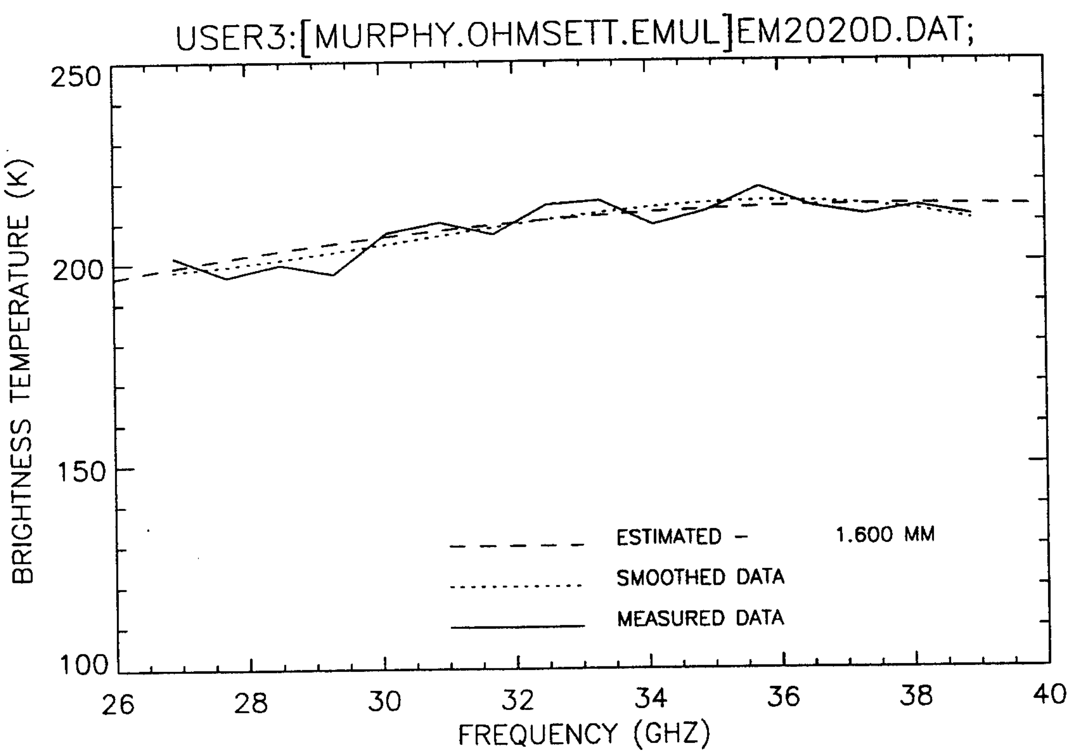

Figure F-12 T^B Versus Frequency Plot for a 2.0 mm Volume of 20% Water-80% Oil Emulsion, 14 October 1994, Pass 4

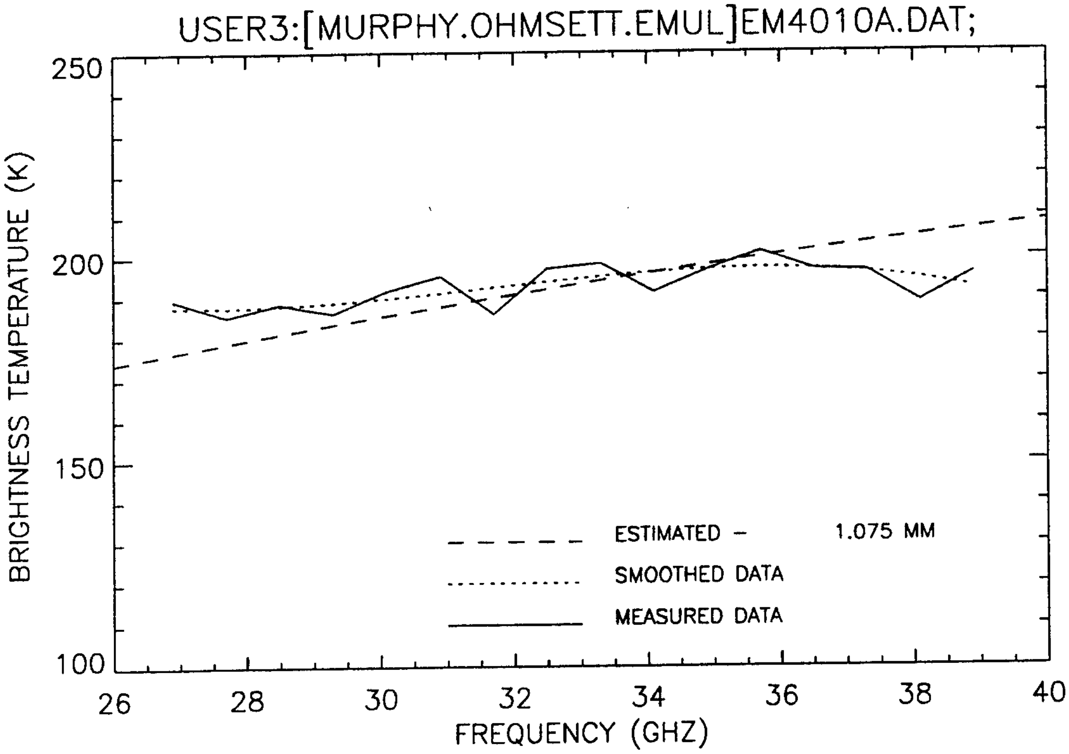

Figure F-13 T^B Versus Frequency Plot for a 1.0 mm Volume of 40% Water-60% Oil Emulsion, 14 October 1994, Pass 1

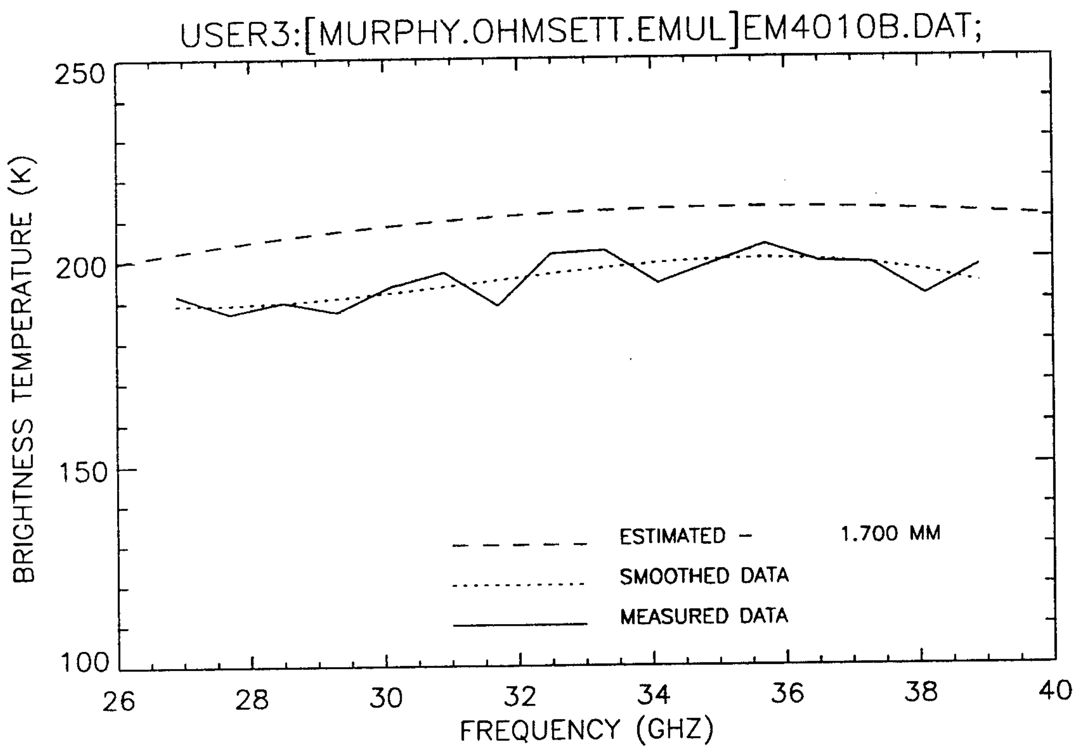

Figure F-14 T^B Versus Frequency Plot for a 1.0 mm Volume of 40% Water-60% Oil Emulsion, 14 October 1994, Pass 2

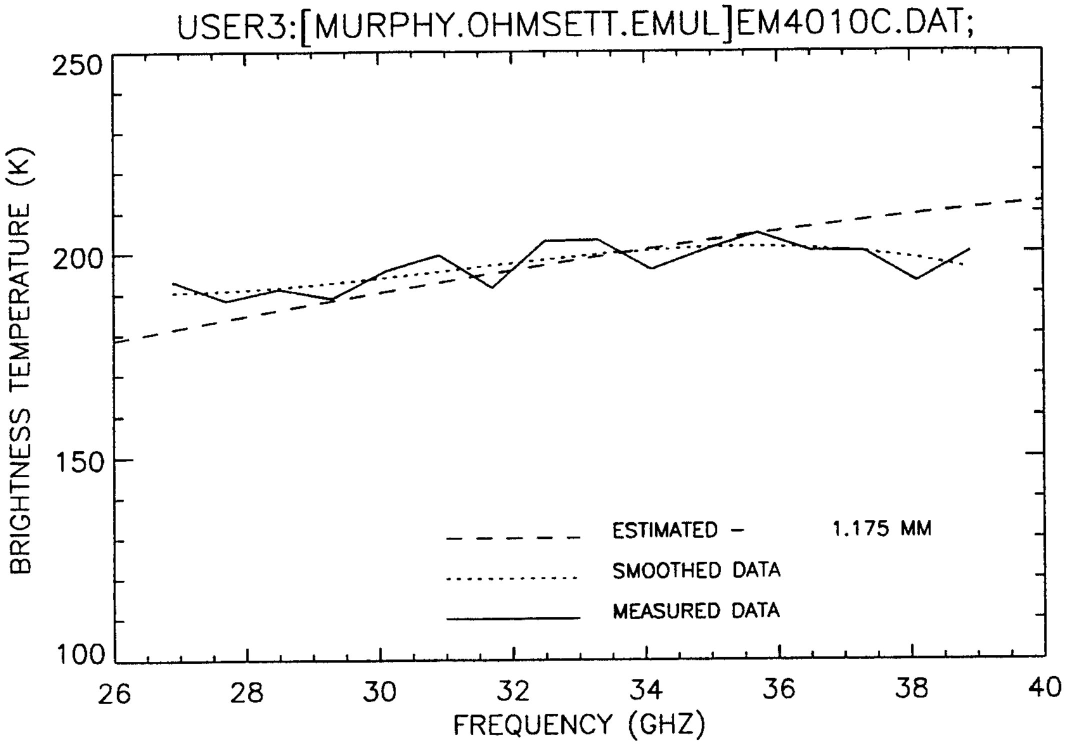

Figure F-15 T^B Versus Frequency Plot for a 1.0 mm Volume of 40% Water-60% Oil Emulsion, 14 October 1994, Pass 3

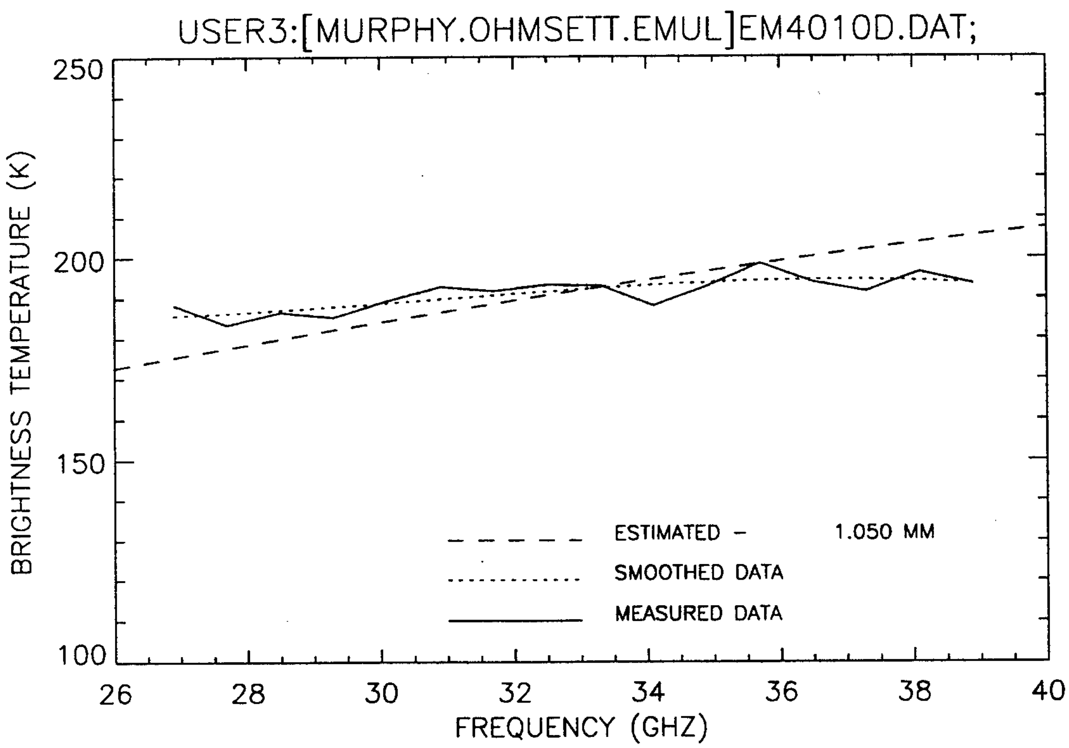

Figure F-16 T^B Versus Frequency Plot for a 1.0 mm Volume of 40% Water-60% Oil Emulsion, 14 October 1994, Pass 1

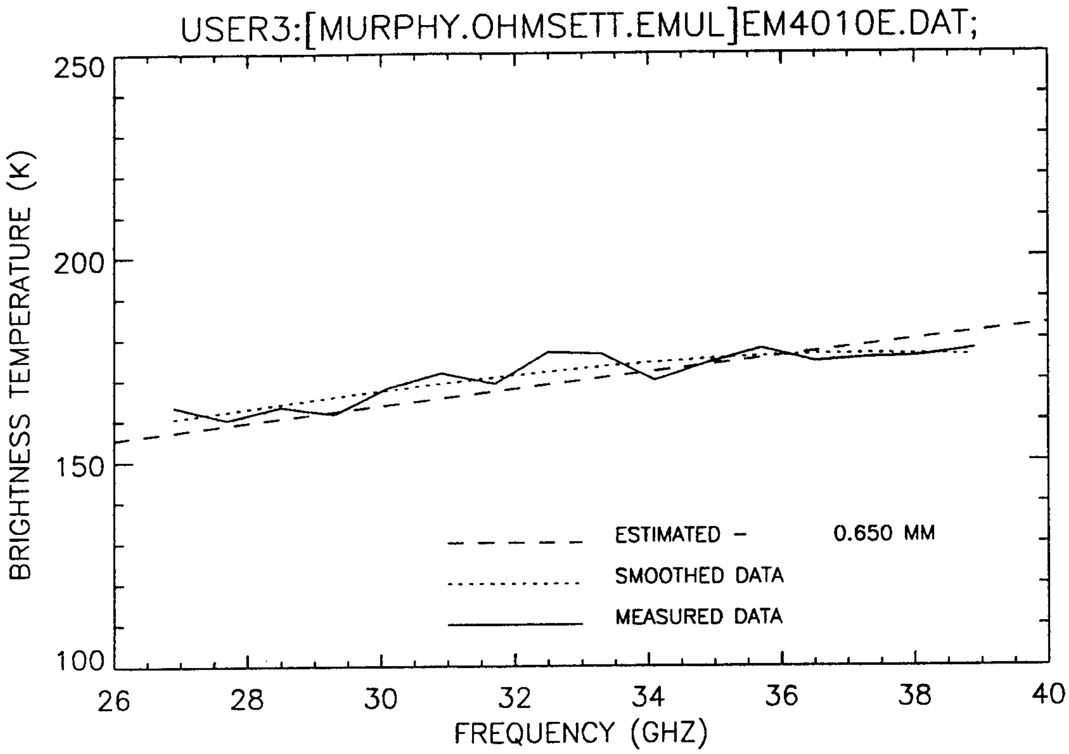

Figure F-17 T^B Versus Frequency Plot for a 1.0 mm Volume of 40% Water-60% Oil Emulsion, 14 October 1994, Pass 1

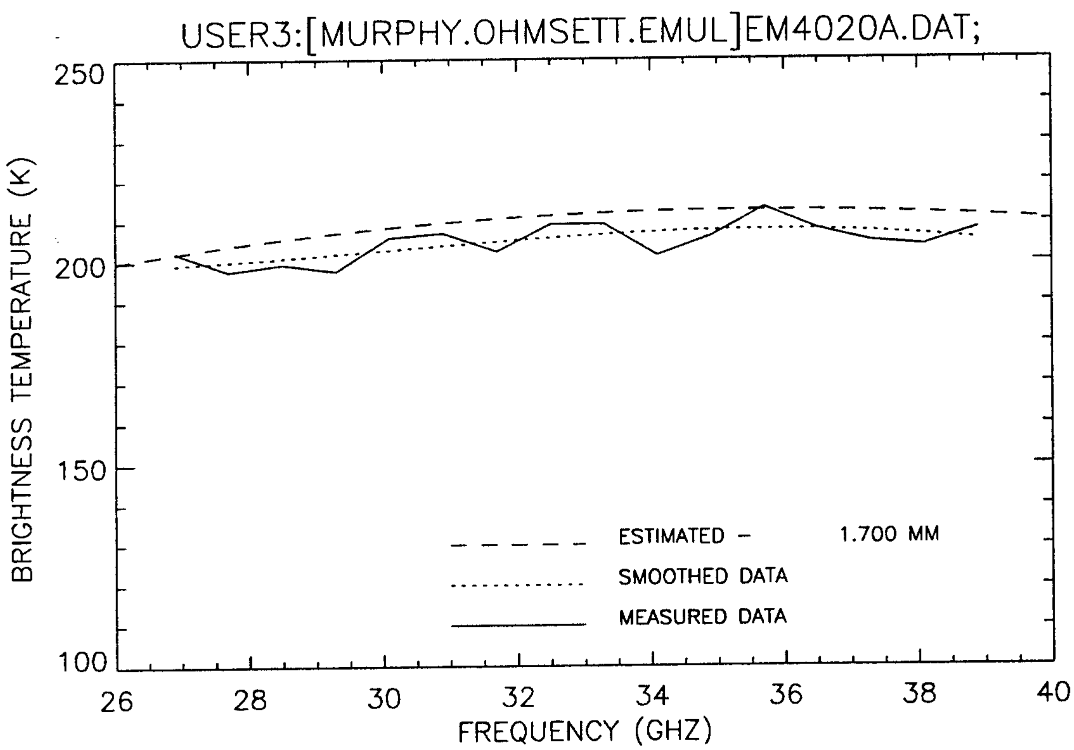

Figure F-18 T^B Versus Frequency Plot for a 2.0 mm Volume of 40% Water-60% Oil Emulsion, 14 October 1994, Pass 1

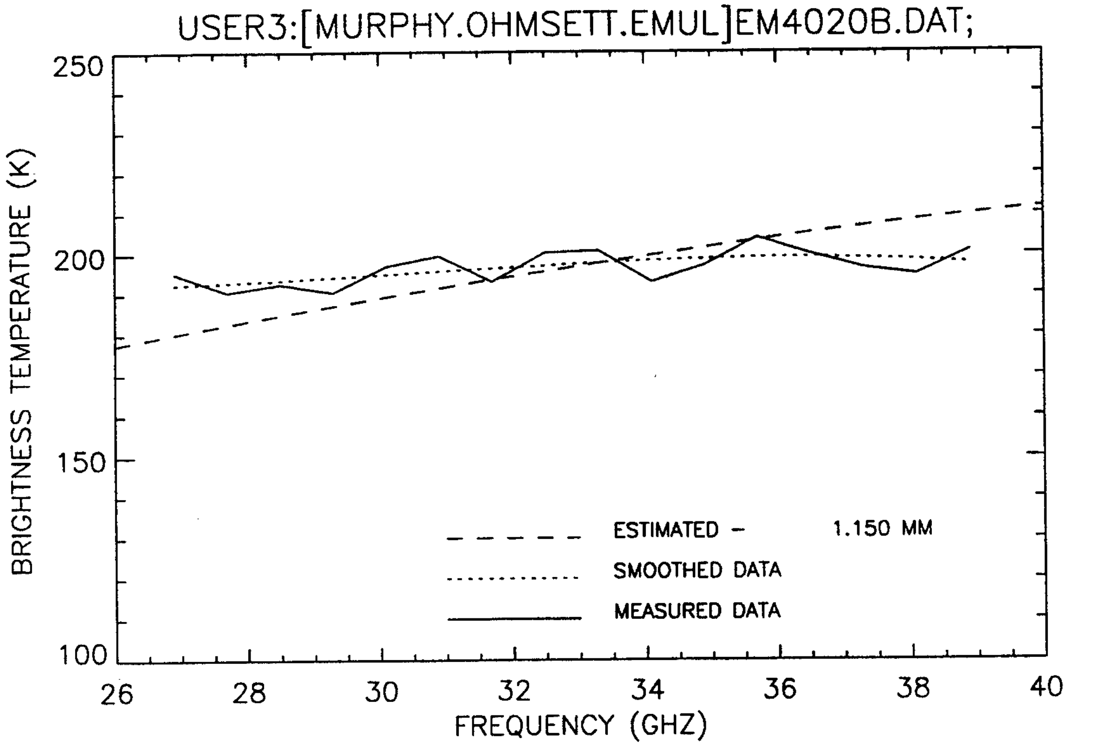

Figure F-19 T^B Versus Frequency Plot for a 2.0 mm Volume of 40% Water-60% Oil Emulsion, 14 October 1994, Pass 2

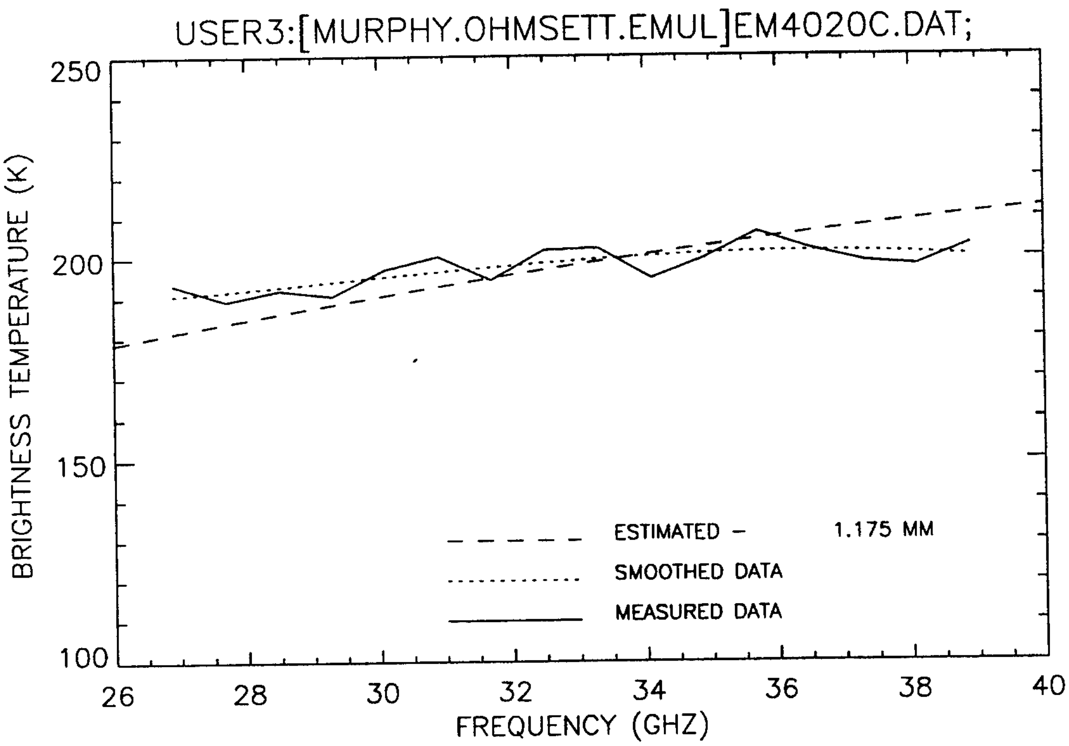

Figure F-20 T^B Versus Frequency Plot for a 2.0 mm Volume of 40% Water-60% Oil Emulsion, 14 October 1994, Pass 3

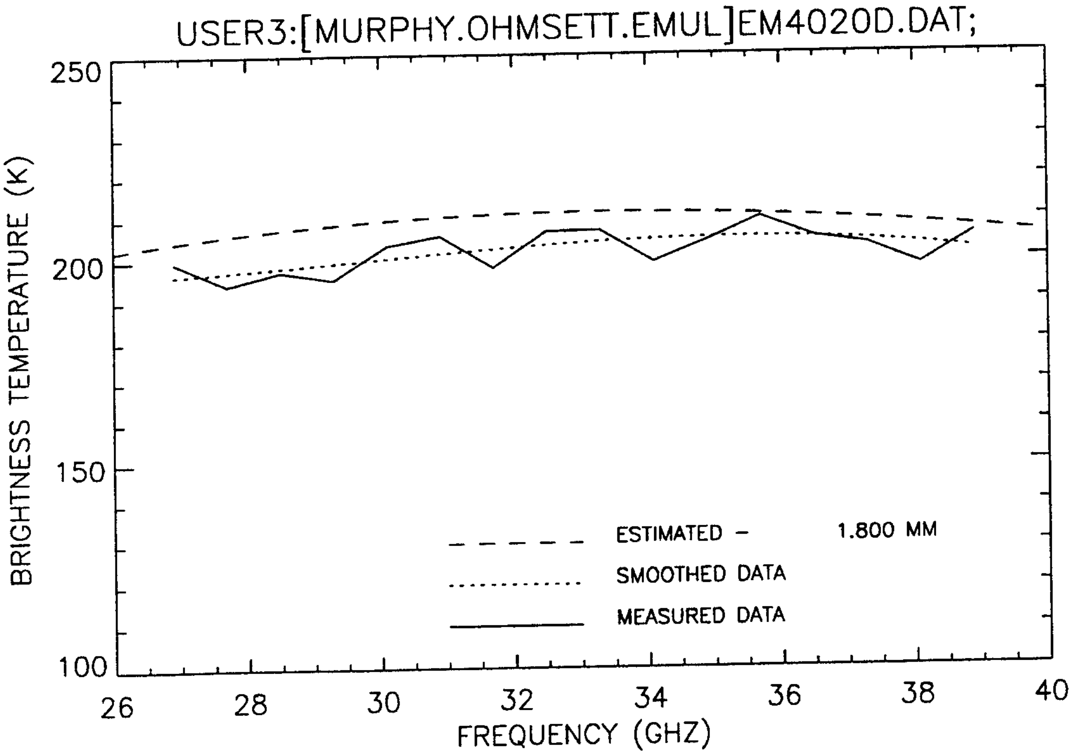

Figure F-21 T^B Versus Frequency Plot for a 2.0 mm Volume of 40% Water-60% Oil Emulsion, 14 October 1994, Pass 4

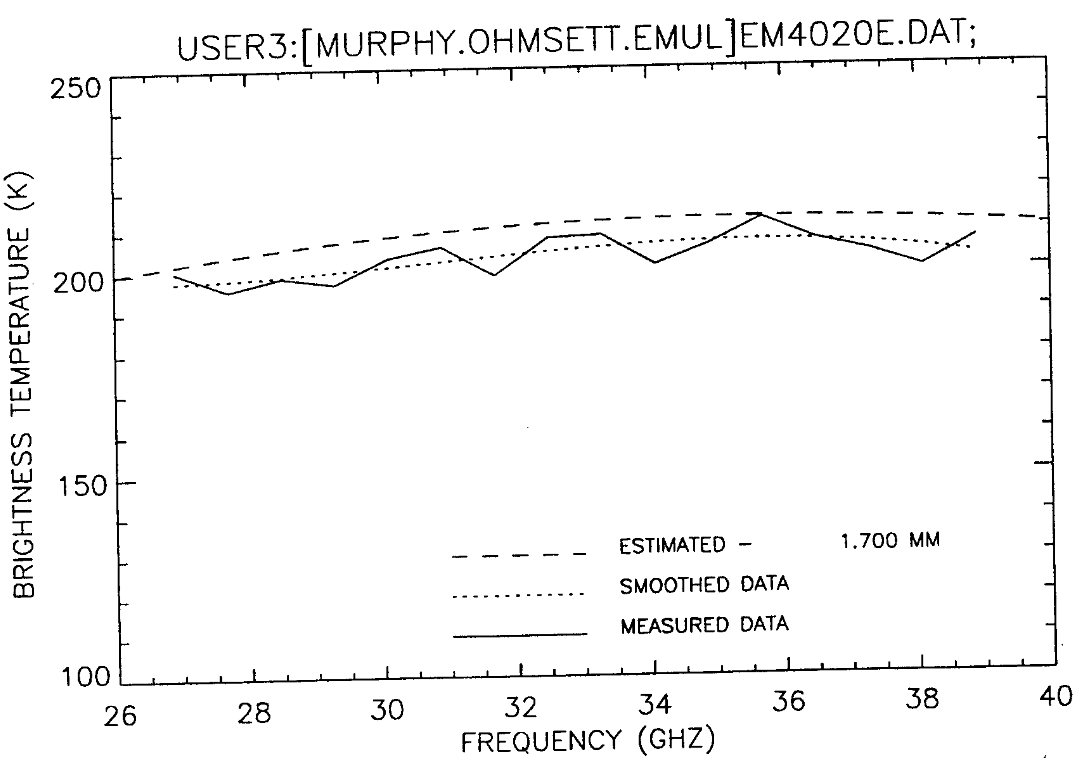

Figure F-22 T^B Versus Frequency Plot for a 2.0 mm Volume of 40% Water-60% Oil Emulsion, 14 October 1994, Pass 5

The wave generator was reset to produce chop 2 wave conditions. After the wave conditions had reached steady-state, measurements were collected over the oil target pools

EW0000A - This curve was chosen to be the background water reference.

EW0000B - This curve is a good match to the algorithm estimate of 0.000 mm, although there are significant noise spikes in the data points below 34 GHz. It is speculated that these noise spikes are caused by sun glinting from the wave surface.

EW0000C - This curve is an fair match to the algorithm estimate of 0.100 mm. This estimate seems high considering that this is a water measurement; the water curve (plotted) is just as good a fit as the algorithm estimate. This measurement also seems to exhibit sun glint-induced noise spikes over the entire band.

This measurement was taken over the 0.5 mm intended thickness, 20%-water/80%-oil target in an area that had an emulsion with a "lumpy" appearance. The antenna beam fill is estimated to be 60%.

EW2005A - This curve is a poor match to the algorithm estimate of 1.025 mm. The shape seems to match the shape of a 1.6 mm estimate, but the overall T^B seems too low. The smoothed curve shape may be a result of the large noise spikes seen in the data. The result is inconclusive.

This measurement was taken over the same lumpy emulsion but now the antenna beam fill is estimated to be 40%.

EW2005B - This curve is a poor-to-fair match to the algorithm estimate of 0.825 mm. It is speculated that the noisy data is due to sun glint effects from the wave surfaces.

EW2005C - This curve is a good-to-excellent match to the algorithm estimate of 0.450 mm.

This measurement was collected over the 1.0 mm intended thickness, 40%-water/60%-oil target in an area where there were scattered emulsion balls, and the beam fill is very low, probably less than 10%.

EW4010A - This curve is a fair match to the algorithm estimate of 0.350 mm.

The main bridge was moved to the 2.0 mm intended thickness, 40%-water/60%-oil target pool. The FSR antenna has a beam fill of approximately 40%.

EW4020A - This curve is a fair match to the algorithm estimate of 0.850 mm.

EW4020B - This curve is a poor match to the algorithm estimate of 0.900 mm. The shape is more characteristic of a 1.8 mm estimate; however, the overall T^B is much too low. The result is inconclusive.

EW4020C - This curve is a fair match to the algorithm estimate of 1.000 mm; however, the slope does seem to be quite flat which is more characteristic of an emulsion.

EW4020D - This curve is a fair match to the algorithm estimate of 0.850 mm; however, the slope does seem to be quite flat which is more characteristic of an emulsion.

This measurement was taken over an area with small (approximately 1-inch) emulsion-balls that were between containment areas. There was a very small beam fill, estimated to be 5 - 10%.

EW40XXA - This curve is an excellent match to the algorithm estimate of 0.250 mm.

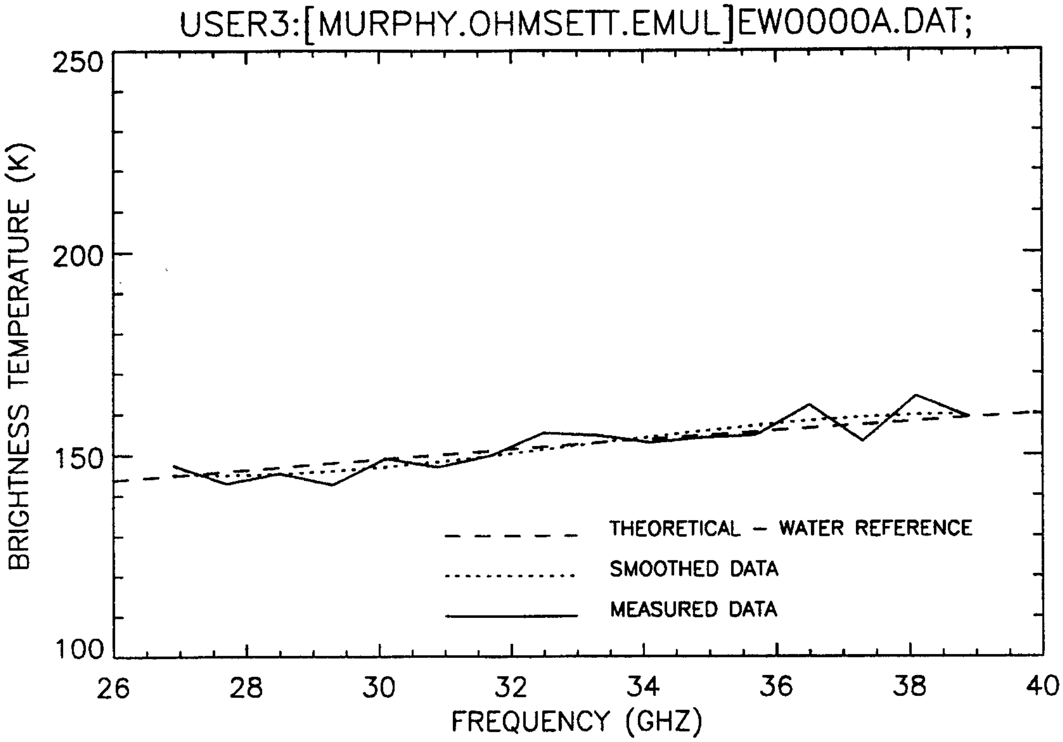

Figure F-23 T^B Versus Frequency Plot for Background Water, Chop Condition 2, 14 October 1994, Pass 1

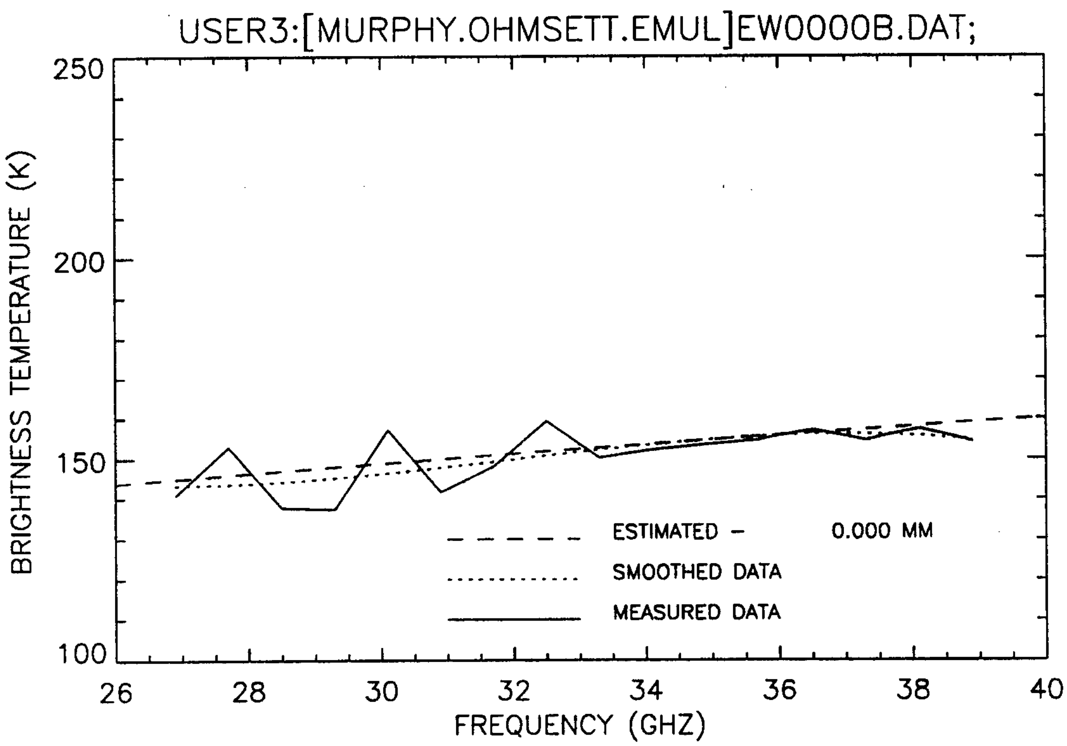

Figure F-24 T^B Versus Frequency Plot for Background Water, Chop Condition 2, 14 October 1994, Pass 2

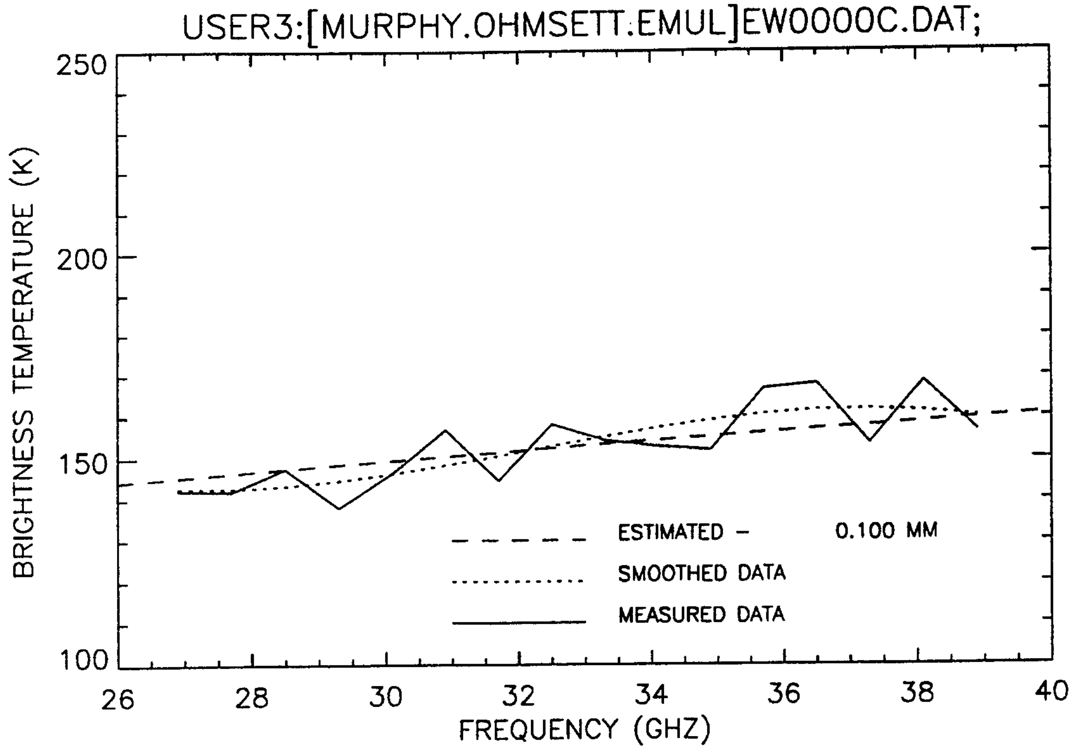

Figure F-25 T^B Versus Frequency Plot for Background Water, Chop Condition 2, 14 October 1994, Pass 3

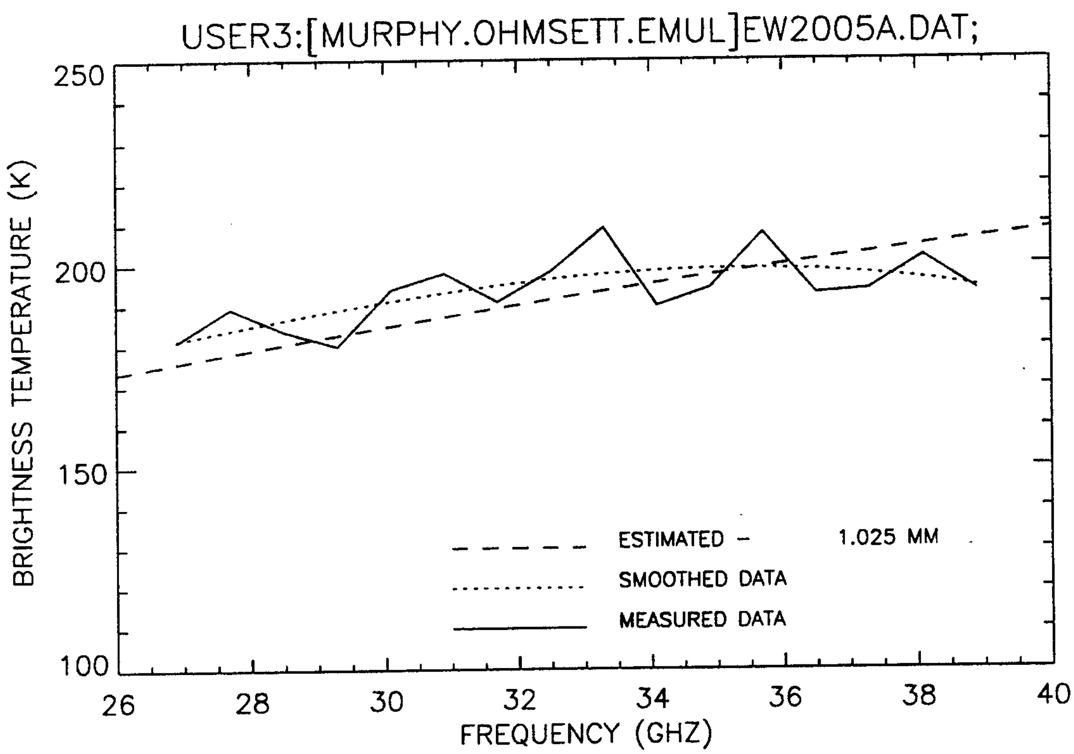

Figure F-26 T^B Versus Frequency Plot for a 0.5 mm Volume of 20% Water-80% Oil Emulsion, Chop Condition 2, 14 October 1994, Pass 1

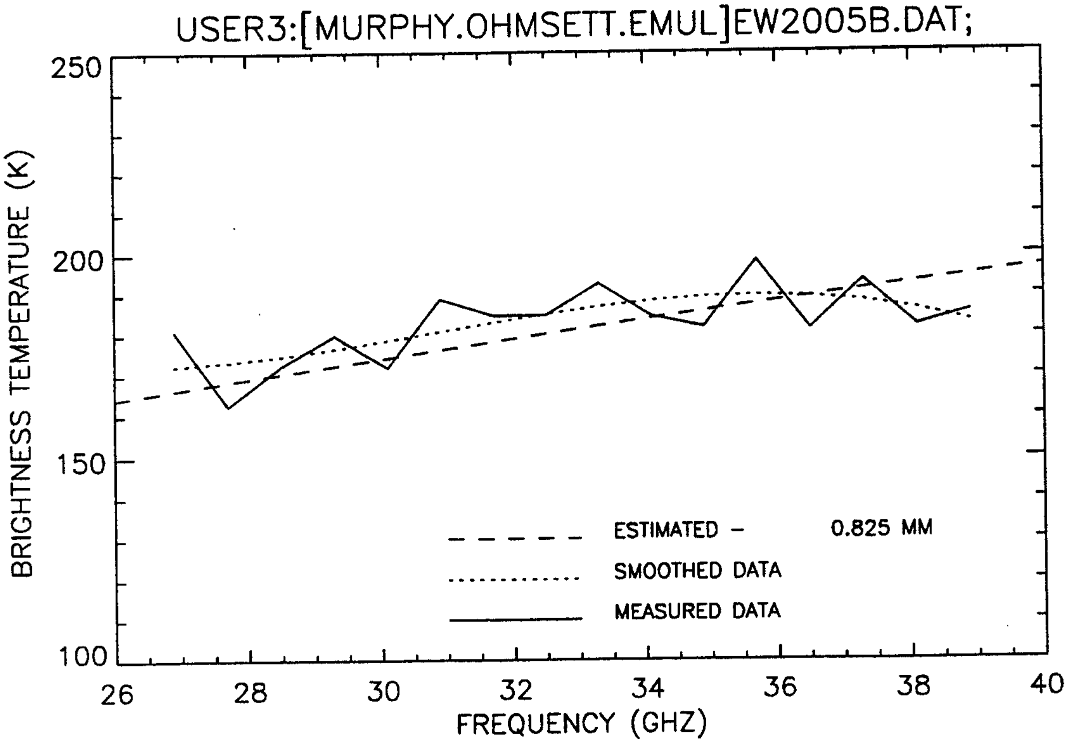

Figure F-27 T^B Versus Frequency Plot for a 0.5 mm Volume of 20% Water-80% Oil Emulsion, Chop Condition 2, 14 October 1994, Pass 2

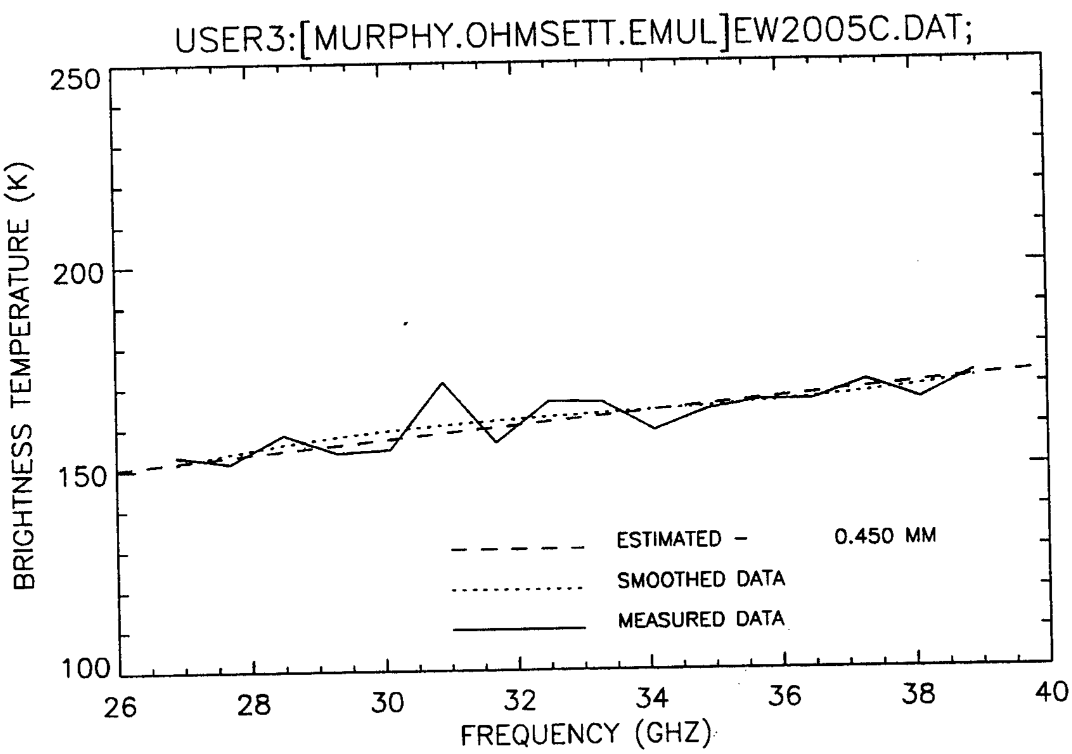

Figure F-28 T^B Versus Frequency Plot for a 0.5 mm Volume of 20% Water-80% Oil Emulsion, Chop Condition 2, 14 October 1994, Pass 3

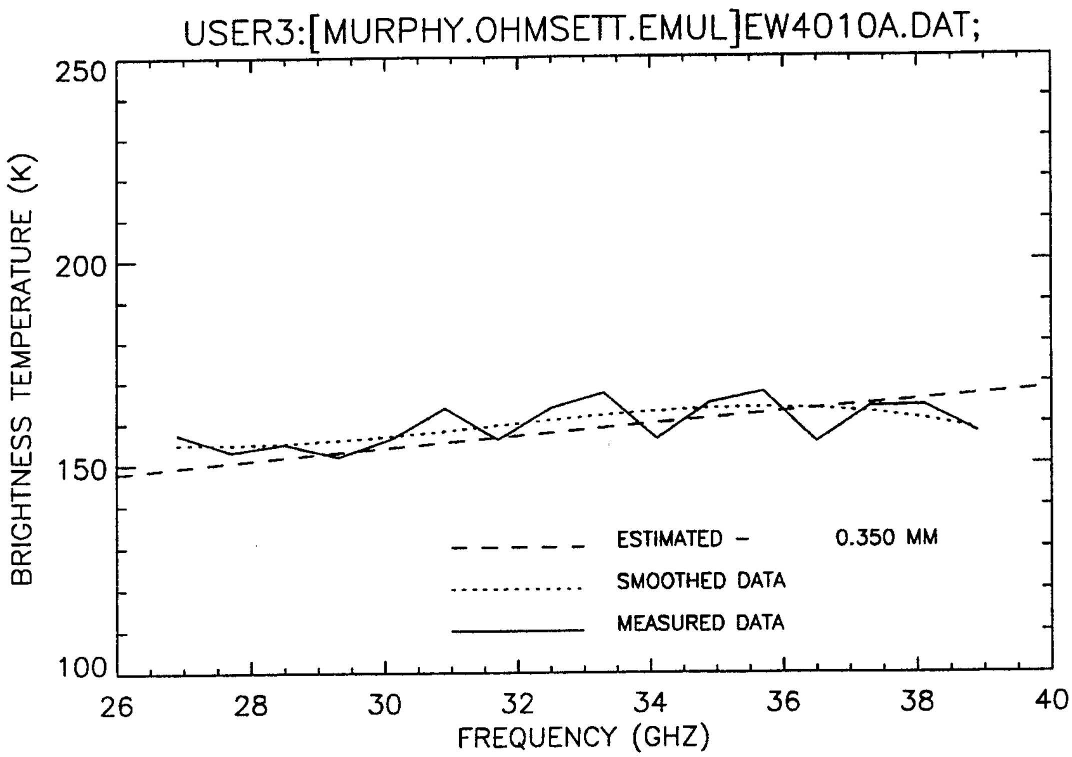

Figure F-29 T^B Versus Frequency Plot for a 1.0 mm Volume of 40% Water-60% Oil Emulsion, Chop Condition 2, 14 October 1994, Pass 1

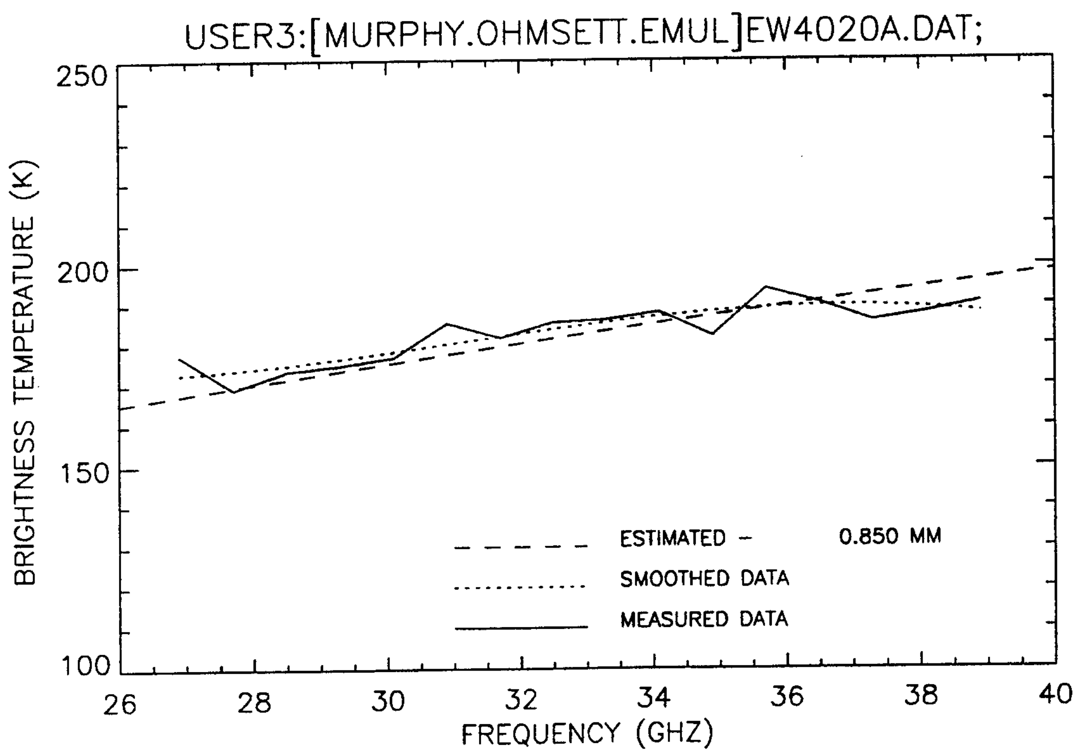

Figure F-30 T^B Versus Frequency Plot for a 2.0 mm Volume of 40% Water-60% Oil Emulsion, Chop Condition 2, 14 October 1994, Pass 1

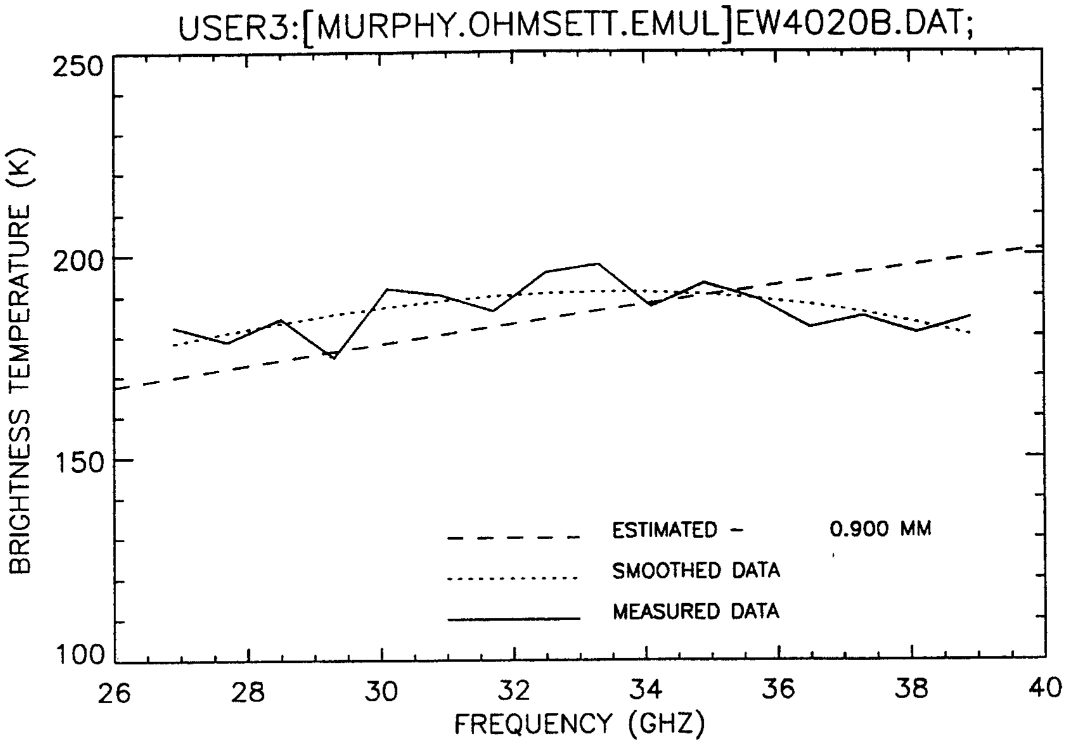

Figure F-31 T^B Versus Frequency Plot for a 2.0 mm Volume of 40% Water-60% Oil Emulsion, Chop Condition 2, 14 October 1994, Pass 2

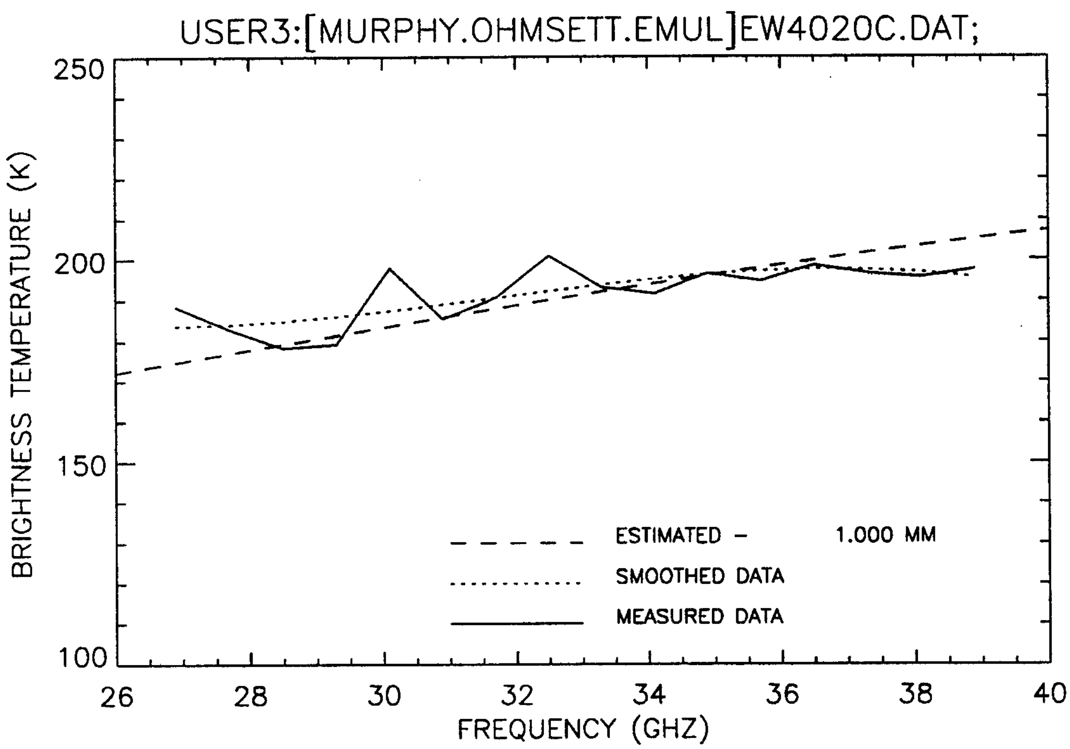

Figure F-32 T^B Versus Frequency Plot for a 2.0 mm Volume of 40% Water-60% Oil Emulsion, Chop Condition 2, 14 October 1994, Pass 3

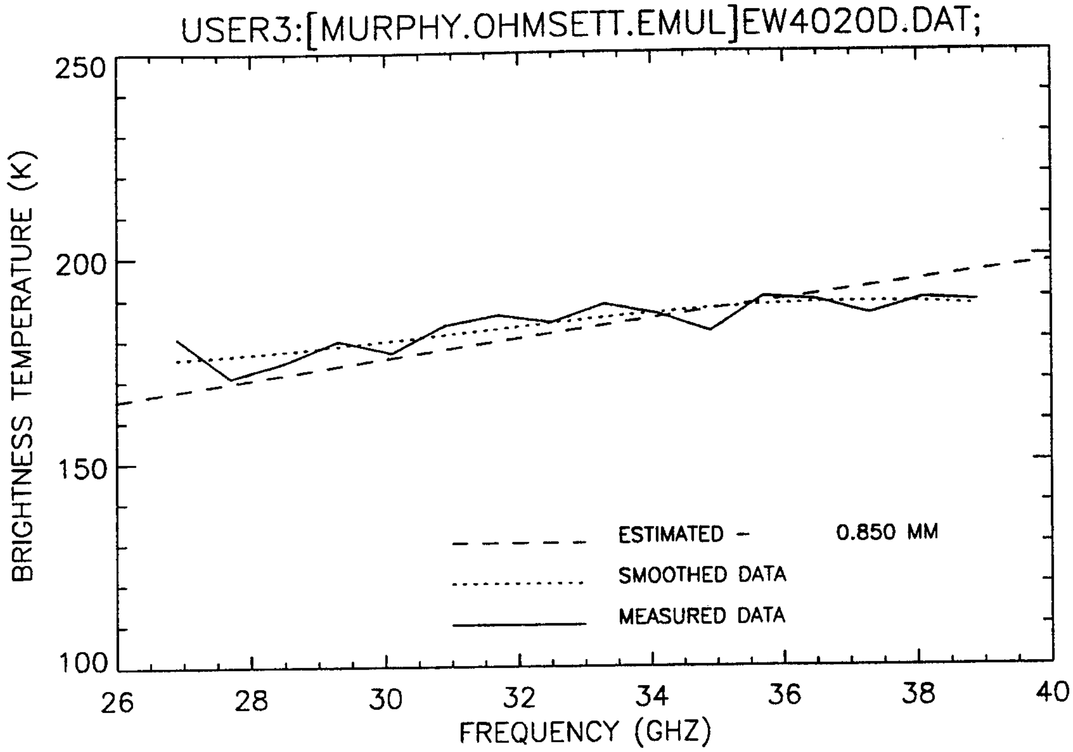

Figure F-33 T^B Versus Frequency Plot for a 2.0 mm Volume of 40% Water-60% Oil Emulsion, Chop Condition 2, 14 October 1994, Pass 4

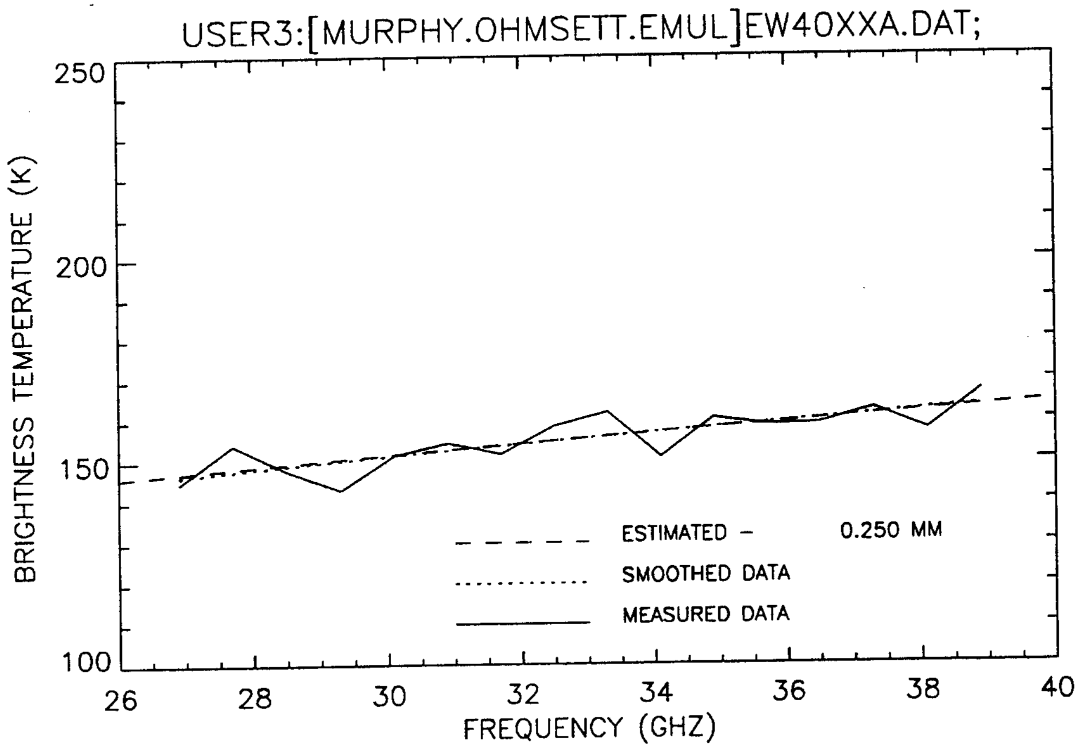

Figure F-34 T^B Versus Frequency Plot for balls of Emulsion between containment areas, Chop Condition 2, 14 October 1994, Pass 1

APPENDIX G

BRIGHTNESS TEMPERATURE VERSUS FREQUENCY PLOTS FROM OHMSETT "UNKNOWNS" TESTS

The frequency scanning radiometer was set up at the OHMSETT facility on the main equipment bridge with the oil pools in the radiometer antenna field of view. Tests were conducted on 19 October 1994 Measurements were taken of oil targets of unknown thickness and composition under two sets of wave conditions and two sets of chop conditions.

The file naming convention used for data files was UNKrpx.DAT, where r is a letter identifier for the wave condition (no letter or 'A' = calm, W = wave condition 1, X = wave condition 2, Y = chop condition 1, Z = chop condition 2), p is the pool identification number, and x is the pass identifier. Thus UNKY6C.DAT was the third pass collected on oil target pool 6, under chop condition 1.

The plots shown in this appendix, figures G-1 through G-128, are radiometric brightness temperature (T^B), expressed in Kelvin (K), as measured by the FSR, versus the measurement frequency in GHz. Under the current FSR software configuration, sixteen equally spaced points between 26.5 GHz and 40.0 GHz are sampled, with each sample period somewhat less than one second. These sixteen points are plotted as 'measured' points. For each data set, the oil thickness estimation algorithm, described in Chapter 4, is used to estimate an oil film thickness. This algorithm derived estimate is displayed with the smoothed curve and the declared result plotted over the actual measured points. The data analyst can then either choose to accept the algorithm estimate, or manually select a curve that may be a better fit to the measured data. Comments are provided for each measurement concerning the fit of the algorithm estimate and the analyst's choice for each curve's best fit.

The plots in this appendix are arranged by test session. At the beginning of each test session data set, comments are provided for each measurement concerning the fit of the algorithm estimate and the analyst's choice for each curve's best fit.

Unless otherwise noted, the antenna footprint is completely full of oil.

The water in the "clean" water target visually appeared to have some contamination on its surface. The following water measurements were collected between the water target (pool 6) and the most southern oil target (pool 5), because the water appeared to be cleaner there.

UNKREFA - This curve is a good match to the algorithm estimate of 0.275 mm. The "false" estimate of oil thickness may be due to a warm-up or calibration error.

UNKREFB - This curve was chosen to be the background water reference, because the overall T^B of UNKREFA seemed too high and the overall T^B of UNKREFC seemed too low, and noisy.

UNKREFC - This curve is a poor match to the algorithm estimate of 0.0 mm. Again, a warm-up or calibration error is suspected.

The main bridge was moved over target pool 1. This target consisted of 0.74 mm of diesel oil that appeared to cover 90% of the oil containment area. Visually, there appeared to be an oil wedge in this pool, with the thicker oil on the northern side. The first three measurements are from the center of the oil target.

UNK01A - This curve is a fair match to the algorithm estimate of 0.8 mm; however, the slight curvature suggests possibility of a thicker oil.

UNK01B - This curve is a poor match to the algorithm estimate of 0.575 mm.

UNK01C - This curve is a poor-to-fair match to the algorithm estimate of 0.45 mm because of its slope; however, the overall curve linearity suggests that it is an oil film less than 1.0 mm.

The main bridge was moved north, approximately halfway between the center of the pool and the oil containment boom. The oil here visually appeared thicker than in the previous three measurements.

UNK01D - This curve is an excellent match to the algorithm estimate of 0.95 mm.

UNK01E - This curve is a fair match to the algorithm estimate of 0.9 mm. The slight curvature suggests the possibility of thicker oil, possibly 4.4 mm as estimated by the correlation only result.

The main bridge was again moved north where the oil appeared thickest, such that the FSR footprint was close to the oil containment boom but did not include the containment boom.

UNK01F - This curve is a poor-to-fair match to the algorithm estimate of 0.975 mm. The slight curvature may suggest the possibility of thicker oil.

UNK01G - This curve is a fair match to the algorithm estimate of 0.975 mm.

The main bridge was moved over oil target 2. This target consisted of 2.6 mm of diesel oil that appeared to cover 100% of the oil containment area. The oil appeared uniformly distributed over the pool. All of the following measurements were collected from the center of the oil target.

UNK02A - Except for frequencies below 29 GHz, this curve is an excellent match to the algorithm estimate of 0.25 mm.

UNK02B -This curve is a good-to-excellent match to the algorithm estimate of 3.45 mm.

UNK02C - This curve is a good match to the algorithm estimate of 3.40 mm.

UNK02D - This curve is a good-to-excellent match to the algorithm estimate of 3.40 mm.

UNK02E - This curve is a good-to-excellent match to the algorithm estimate of 3.40 mm.

The on-site measurement comparisons to the theoretical predictions indicated that the oil thickness in pool 2 was either 0.7 mm or on the order of 3.5 mm. Additional measurement sweeps from both the north and south side of the target were collected. The following set of measurements is from the north side of the target.

UNKA2A - This curve is a good-to-excellent match to the algorithm estimate of 3.875.

UNKA2B - This curve is a good match to the algorithm estimate of 3.800 mm.

UNKA2C - This curve is a fair match to the algorithm estimate of 3.600 mm. This measurement seems noisy compared to the UNKA2A, UNKA2B and UNKA2C measurements that were collected over the same oil target.

UNKA2D - This curve is a good-to-excellent match to the algorithm estimate of 3.650 mm.

The main bridge was moved to collect data from the south side of oil target 2.

UNKA2E - This curve is a poor match to the algorithm estimate of 0.600 mm. The curve also is not a good match to estimates in the 3.5 - 4.0 mm range. The result is inconclusive.

UNKA2F - This curve is a good match to the algorithm estimate of 3.475 mm.

UNKA2G - This curve is an excellent match to the algorithm estimate of 3.25 mm.

UNKA2H - This curve is a poor-to-fair match to the algorithm estimate of 3.525 mm. The curve looks similar in appearance to the UNKA2E plot, and doesn't seem to match the theoretical prediction well. A review of the on-site notes and down-looking video do not reveal any clues to the poor results. The result is inconclusive.

The main bridge was moved to oil target pool 3. This target consisted of 2.0 mm of a mixture of 75% diesel oil 25% crude oil that appeared to cover 100% of the oil containment area. The following measurements are from the center of the target.

UNK03A -This curve is a fair match to the algorithm estimate of 2.125 mm; however, it would match most any T^B curve in the range from 1.9 - 2.2 mm.

UNK03B - This curve is a good match to the algorithm estimate of 2.2 mm; however, it would match most any T^B curve in the range from 1.9 - 2.2 mm.

UNK03C - This curve is a fair match to the algorithm estimate of 2.125 mm; however, it would match most any T^B curve in the in range from 1.9 - 2.2 mm.

UNK03D - This curve is a poor match to the algorithm estimate of 1.05 mm. It has a very flat T^B response. The result is inconclusive.

The main bridge was moved to the north side of the oil target because visually it appeared to be somewhat thicker oil.

UNK03E -This curve is a fair match to the algorithm estimate of 1.9 mm. It shows some shape characteristics (peaking) corresponding to a 5.5 mm estimate.

UNK03F - This curve is a fair-to-good match to the algorithm estimate of 2.15 mm.

UNK03G - This curve is a fair-to-good match to the algorithm estimate of 2.1 mm.

UNK03H - This curve is a good-to-excellent match to the algorithm estimate of 2.20 mm.

The main bridge was moved to oil target pool 4. This target consisted of 1.7 mm of a mixture of 50% diesel oil and 50% waste oil that appeared to cover 60% of the oil containment area. This oil target has a "swirly" area that was a different color and texture from the other parts of the pool. Visually this area looked like an emulsion. The following three measurements were collected in the vicinity of this "swirly" area.

UNK04A - This curve is a poor match to the algorithm estimate of 1.675 mm. It exhibits emulsion traits, and a somewhat flat response with an overall high T^B near 250° K. There is a slight shape characteristic similar to an 8.0 mm estimate, although the amplitude modulation is much too small.

UNK04B - This curve is a poor match to the algorithm estimate of 1.675 mm. It exhibits emulsion traits, and a somewhat flat response with an overall high T^B near 250° K. There is a slight shape characteristic similar to an 8.0 mm estimate, although the amplitude modulation is much too small.

UNK04C - This curve is a poor match to the algorithm estimate of 1.675 mm. It exhibits emulsion traits, and a somewhat flat response with an overall high T^B near 250° K. There is a slight shape characteristic similar to an 8.0 mm estimate, although the amplitude modulation is much too small.

The main bridge was moved so that the FSR could collect data from an area north of the "swirly" oil. The antenna beam was filled with an oil target that was a dark red color, with a uniform distribution and a flat surface (no capillary waves due to wind) that did not contain any bubbles or other contamination.

UNK04D - This curve is a good match to the algorithm estimate of 1.4 mm.

UNK04E - This curve is a good match to the algorithm estimate of 1.6 mm.

UNK04F - This curve is a good match to the algorithm estimate of 1.4 mm.

The main bridge was moved to oil target pool 5. This target consisted of 2.5 mm of a mixture of 75% diesel oil and 25% waste oil that appeared to cover 100% of the oil containment area. The oil target was a dark red color, with inclusions of a brownish, somewhat flaky looking substance that had a higher concentration at the south end of the pool than at the north end. The target had a uniform distribution and a flat surface (no capillary waves due to wind) that did not contain any bubbles. The following measurements are from the center of the oil target.

UNK05A - This curve is a poor match to the algorithm estimate of 1.7 mm. It exhibits emulsion traits, and a somewhat flat response with an overall high T^B near 250° K.

UNK05B - This curve is a poor match to the algorithm estimate of 1.7 mm. It exhibits emulsion traits, and a somewhat flat response with an overall high T^B near 250° K.

UNK05C - This curve is a poor match to the algorithm estimate of 1.75 mm. It exhibits emulsion traits, and a somewhat flat response with an overall high T^B near 250° K. There is a slight shape characteristic similar to a 5.8 mm estimate, although the amplitude modulation is much too small.

UNK05D - This curve is poor match to the algorithm estimate of 1.75 mm. It exhibits emulsion traits, and a somewhat flat response with an overall high T^B near 250° K.

The main bridge was moved for the FSR to measure the oil along the north edge of the containment pool. The following two measurements have a lower percentage fill (the percentage was not recorded) of the brownish inclusion because there was a sparser distribution of the brownish inclusion in this part of the oil target.

UNK05E - This curve is an excellent match to the algorithm estimate of 2.25 mm.

UNK05F - This curve is a poor match to the algorithm estimate of 2.25 mm. It has a shape characteristic similar to a 3.0 mm estimate, although the overall T^B of the measurement is too high.

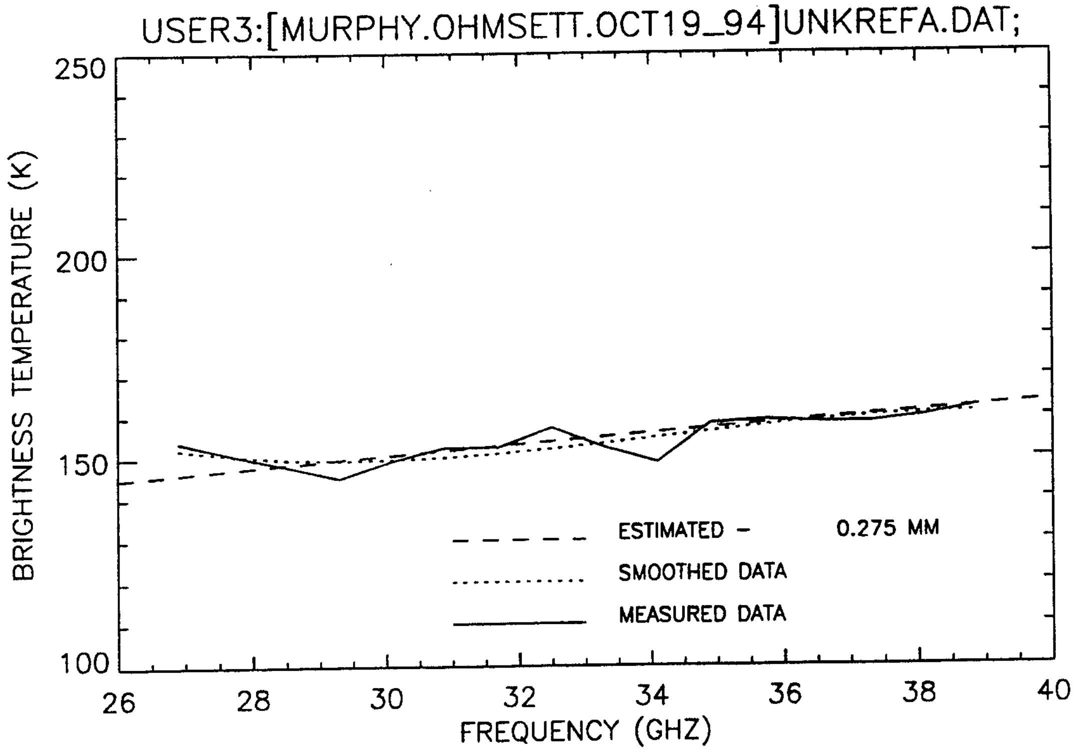

Figure G-1 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, 19 October 1994, Pass 1

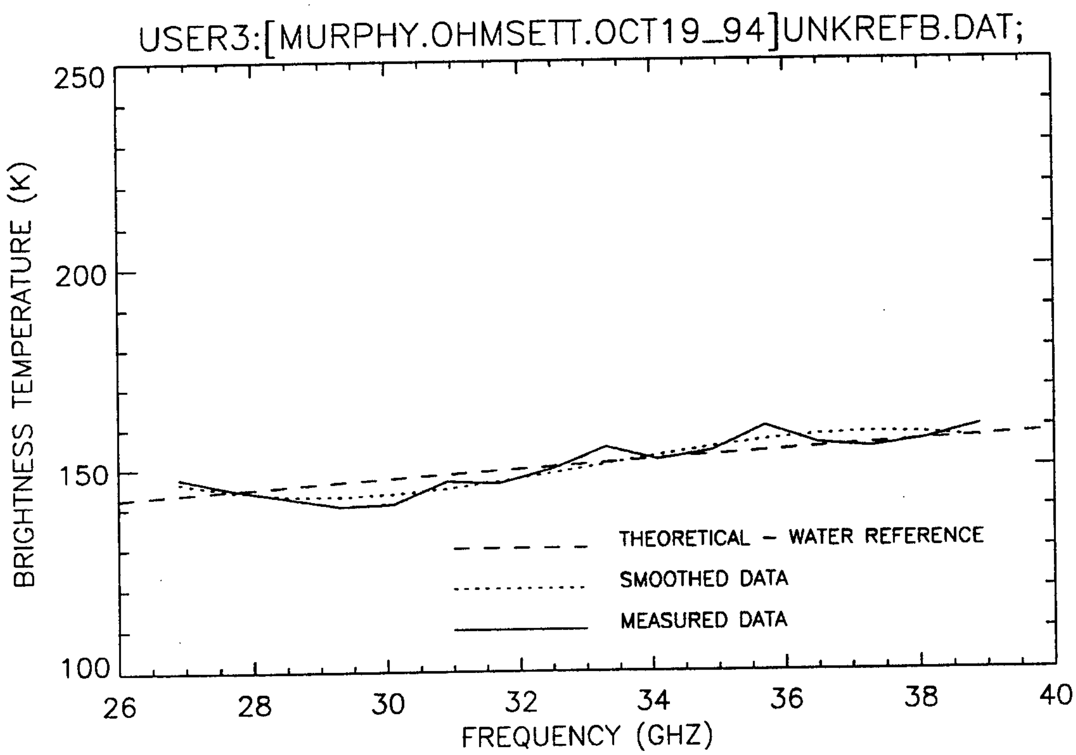

Figure G-2 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, 19 October 1994, Pass 2

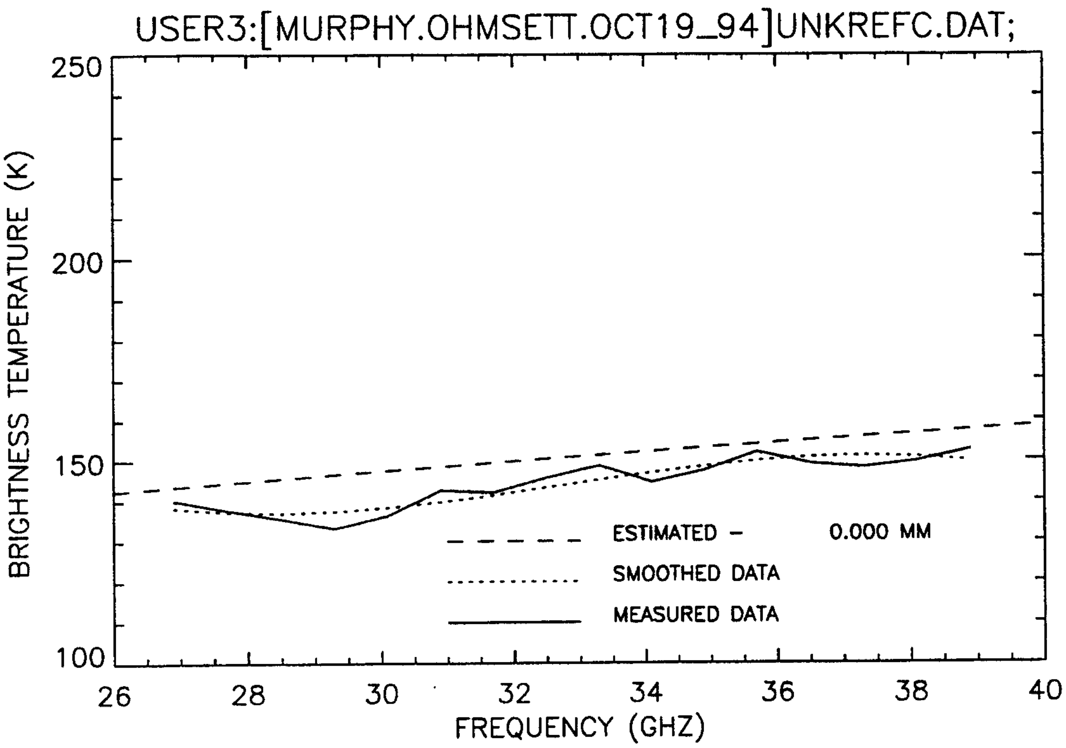

Figure G-3 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, 19 October 1994, Pass 3

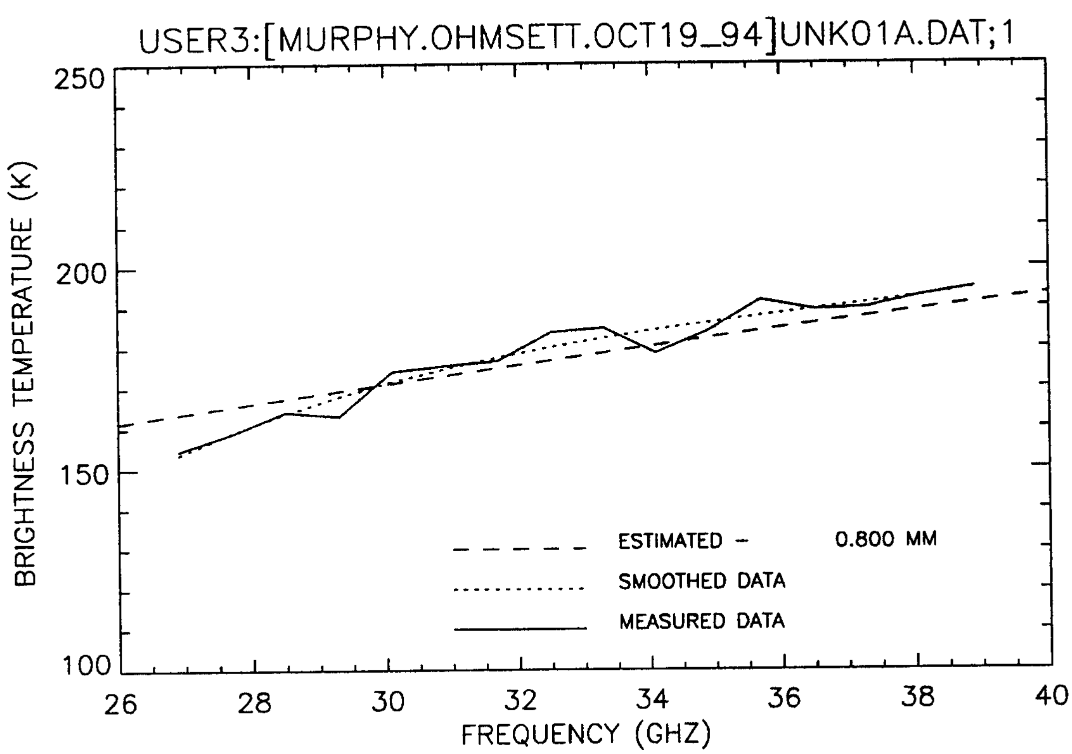

Figure G-4 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, 19 October 1994, Pass 1

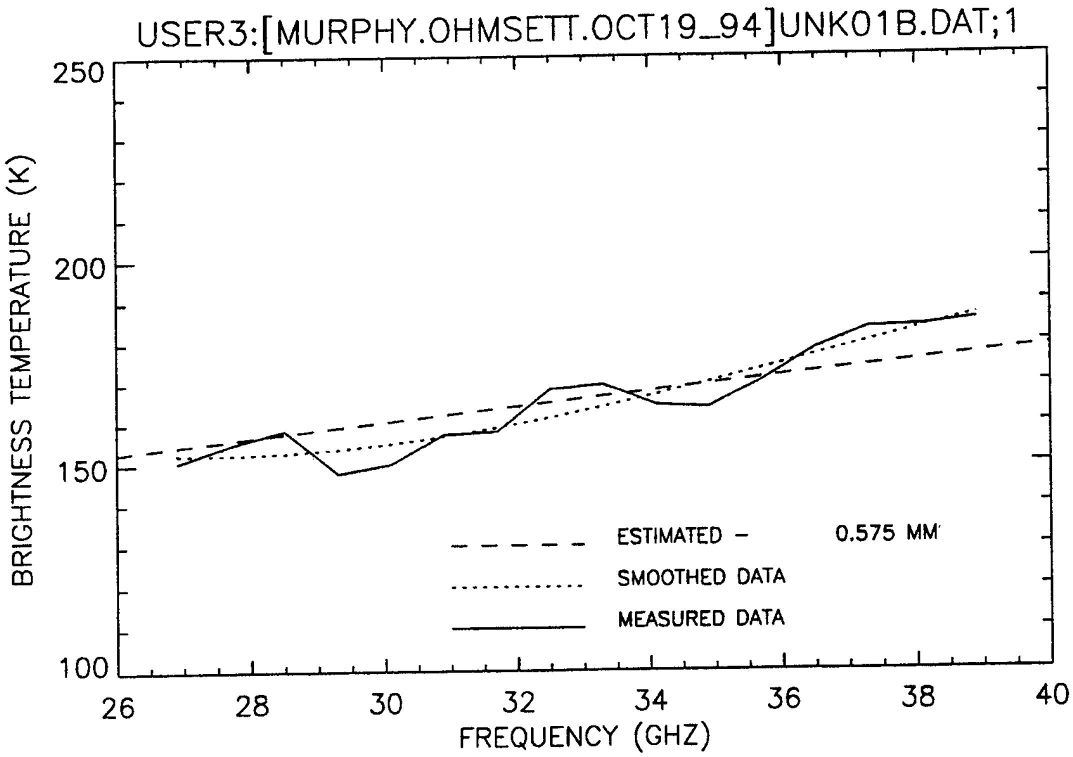

Figure G-5 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, 19 October 1994, Pass 2

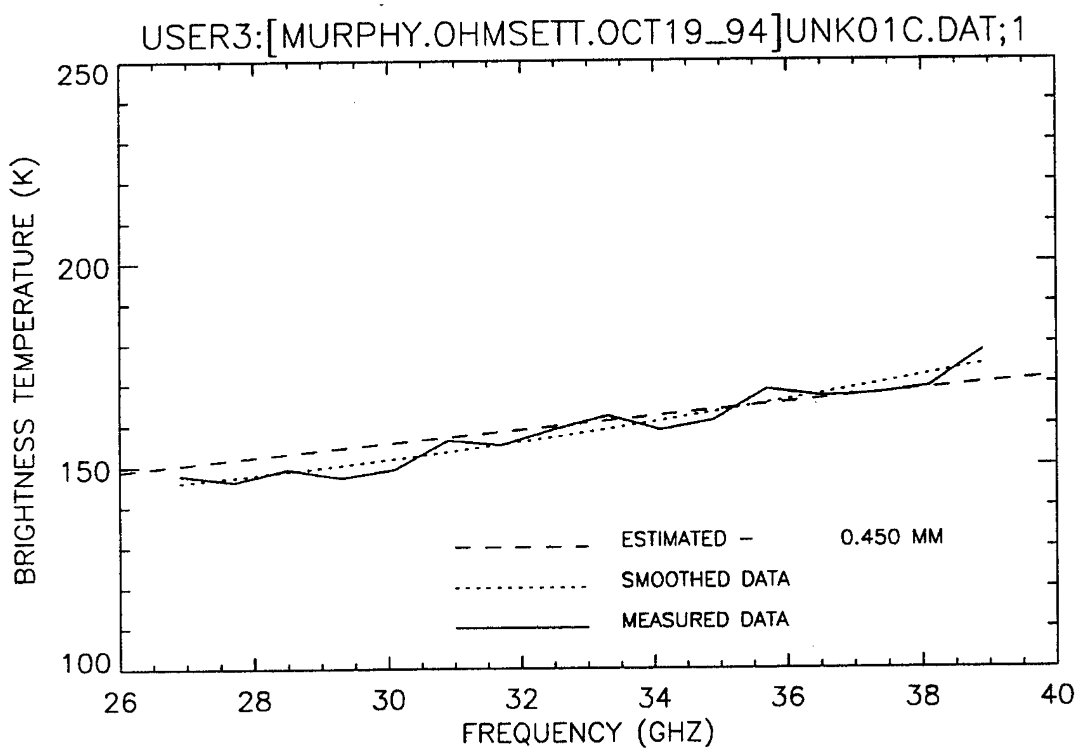

Figure G-6 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, 19 October 1994, Pass 3

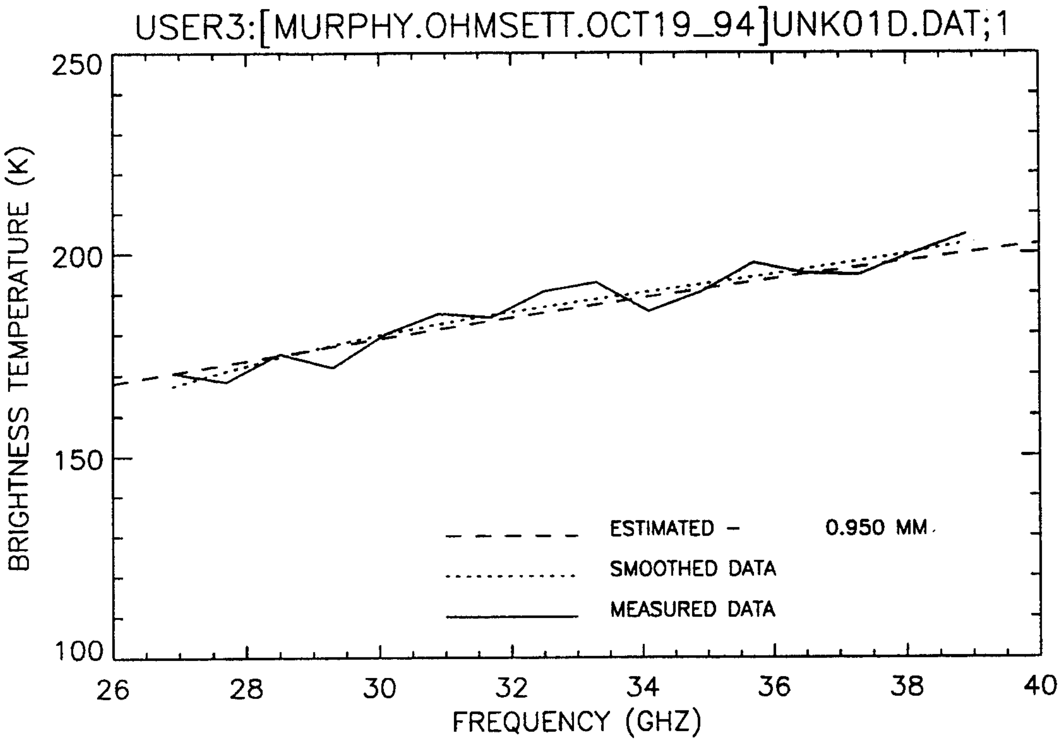

Figure G-7 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, 19 October 1994, Pass 4

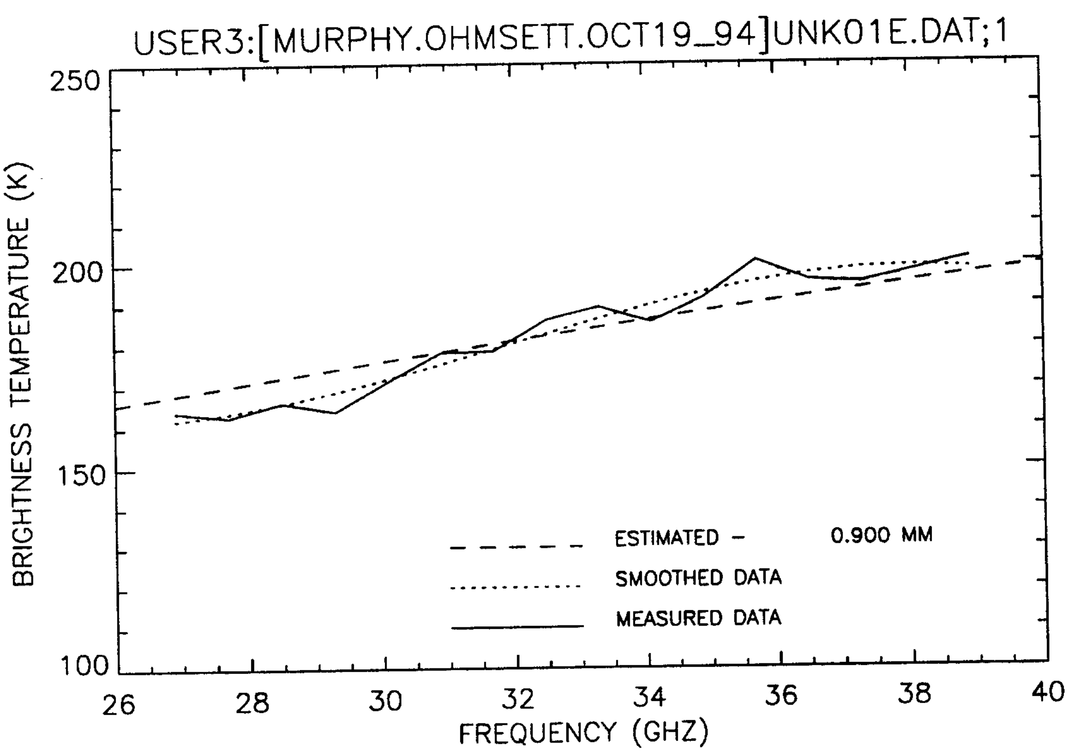

Figure G-8 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, 19 October 1994, Pass 5

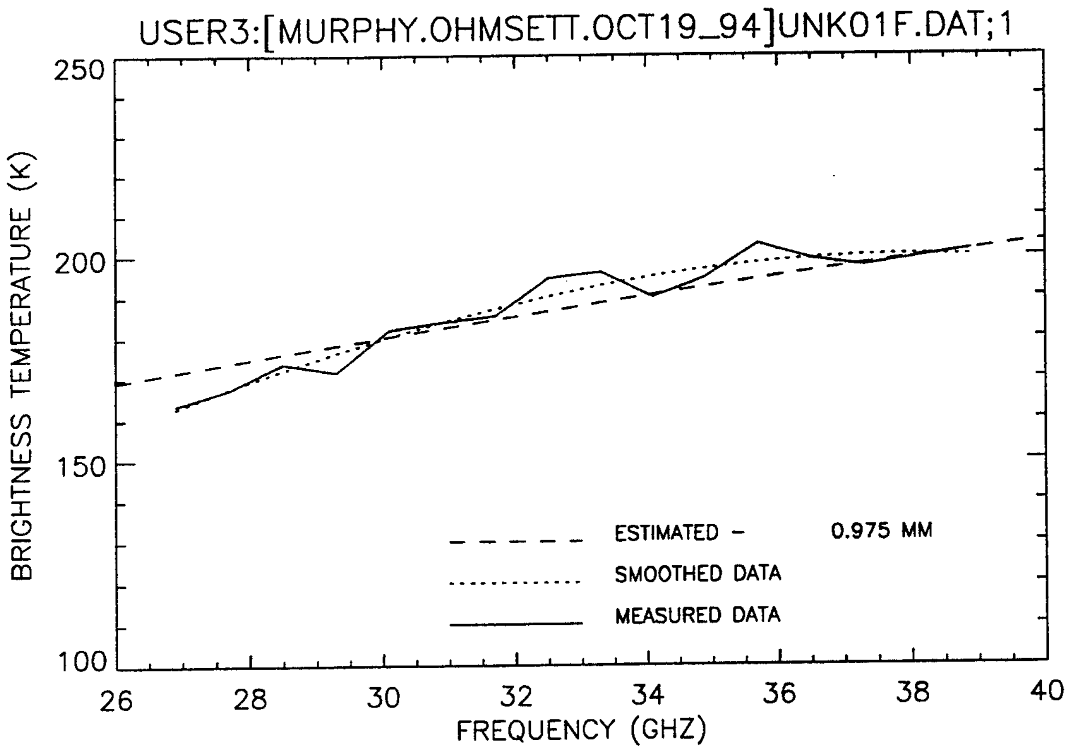

Figure G-9 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, 19 October 1994, Pass 6

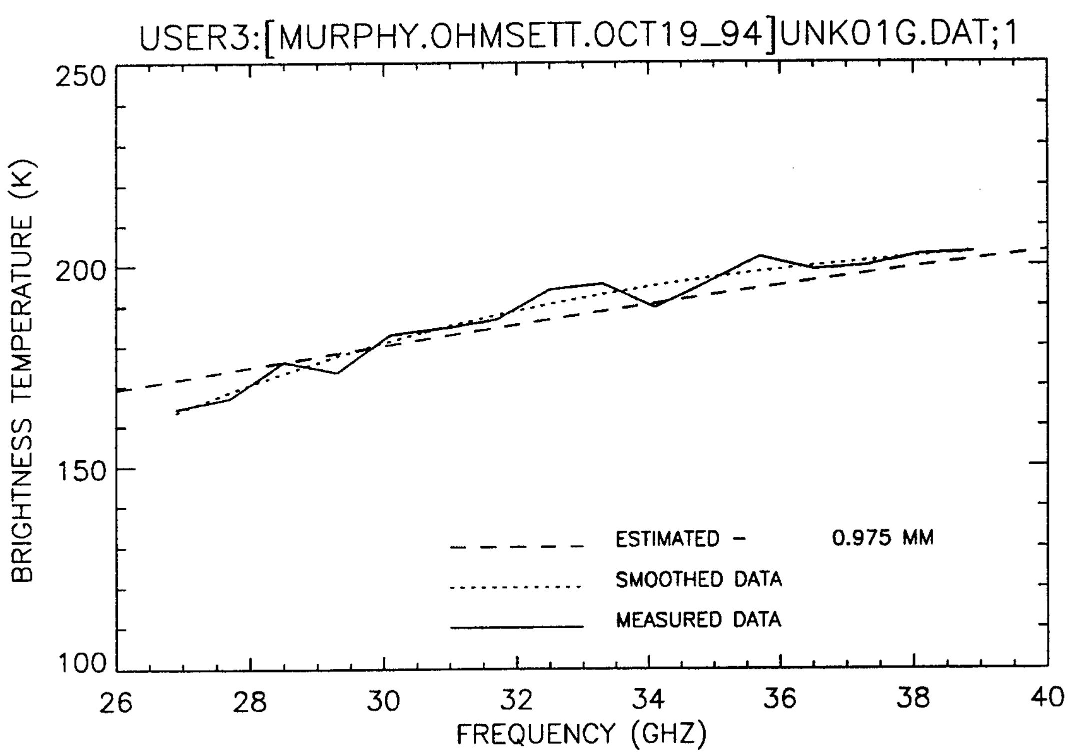

Figure G-10 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, 19 October 1994, Pass 7

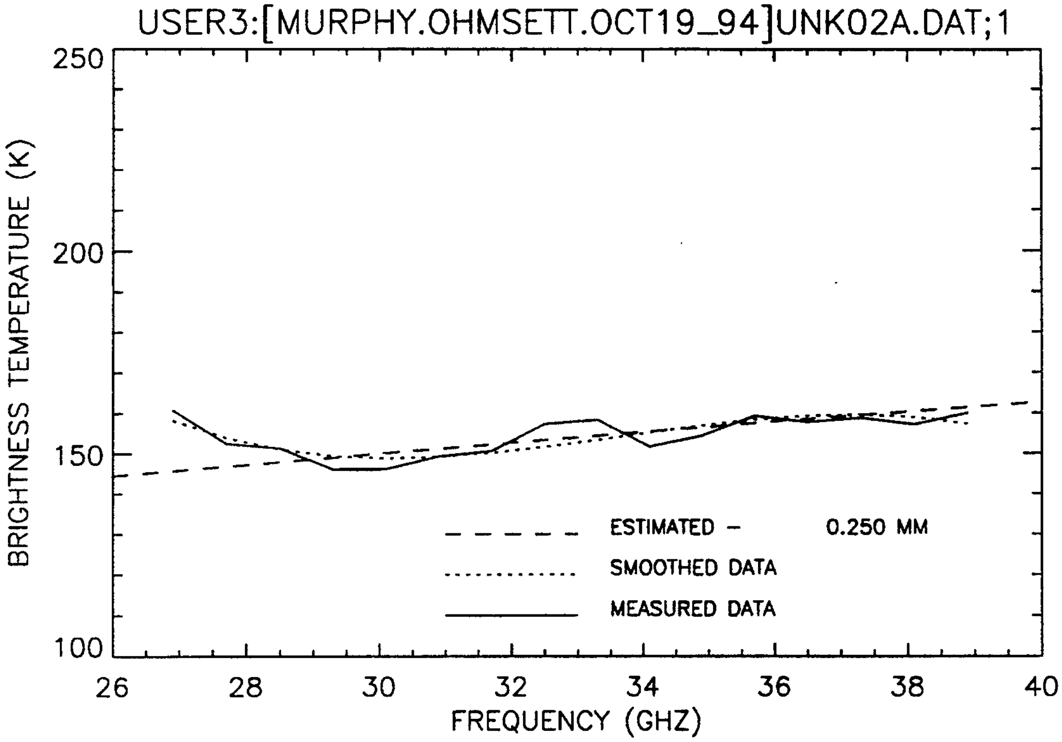

Figure G-11 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, 19 October 1994, Pass 1

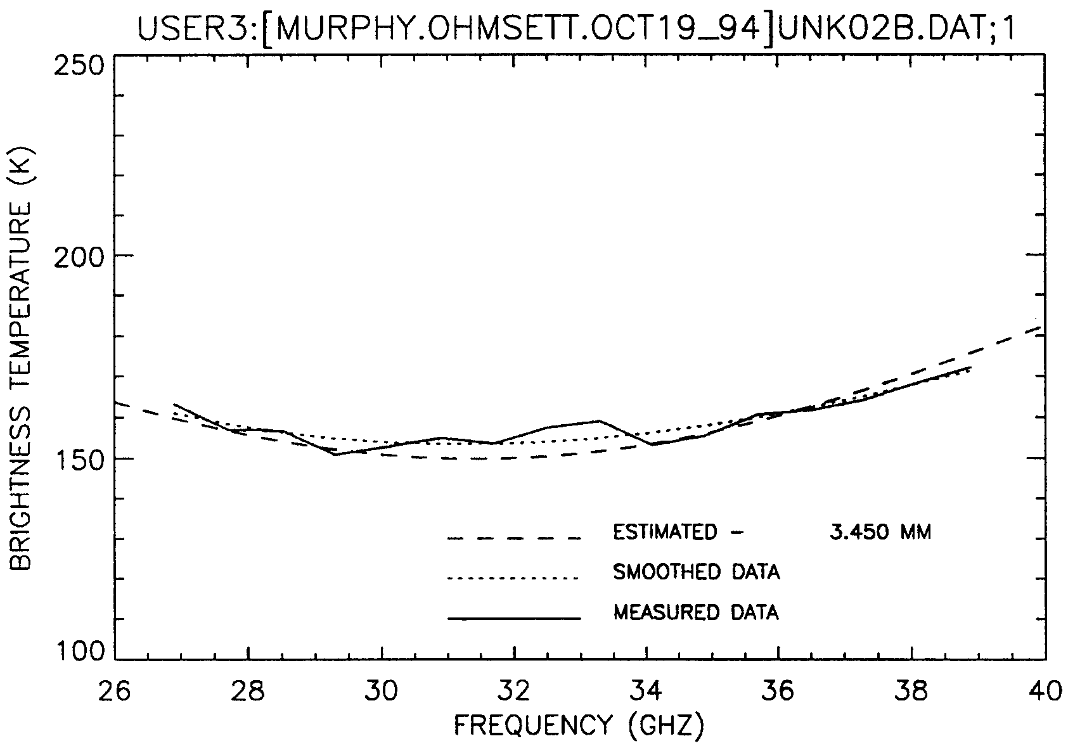

Figure G-12 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, 19 October 1994, Pass 2

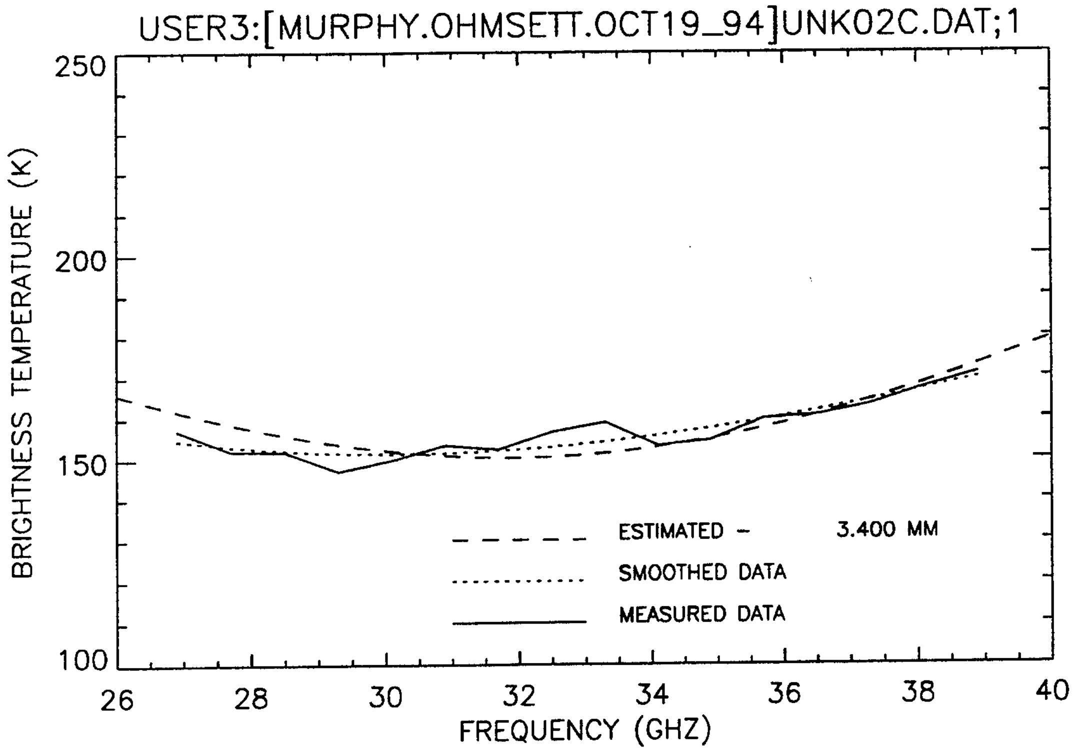

Figure G-13 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, 19 October 1994, Pass 3

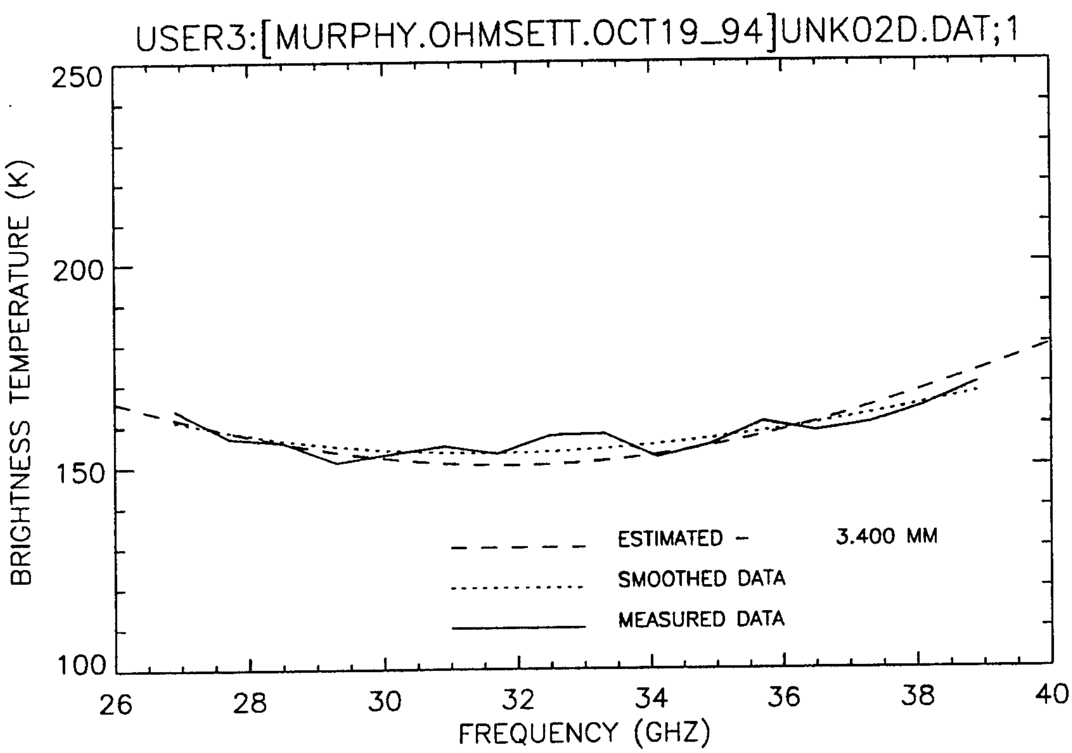

Figure G-14 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, 19 October 1994, Pass 4

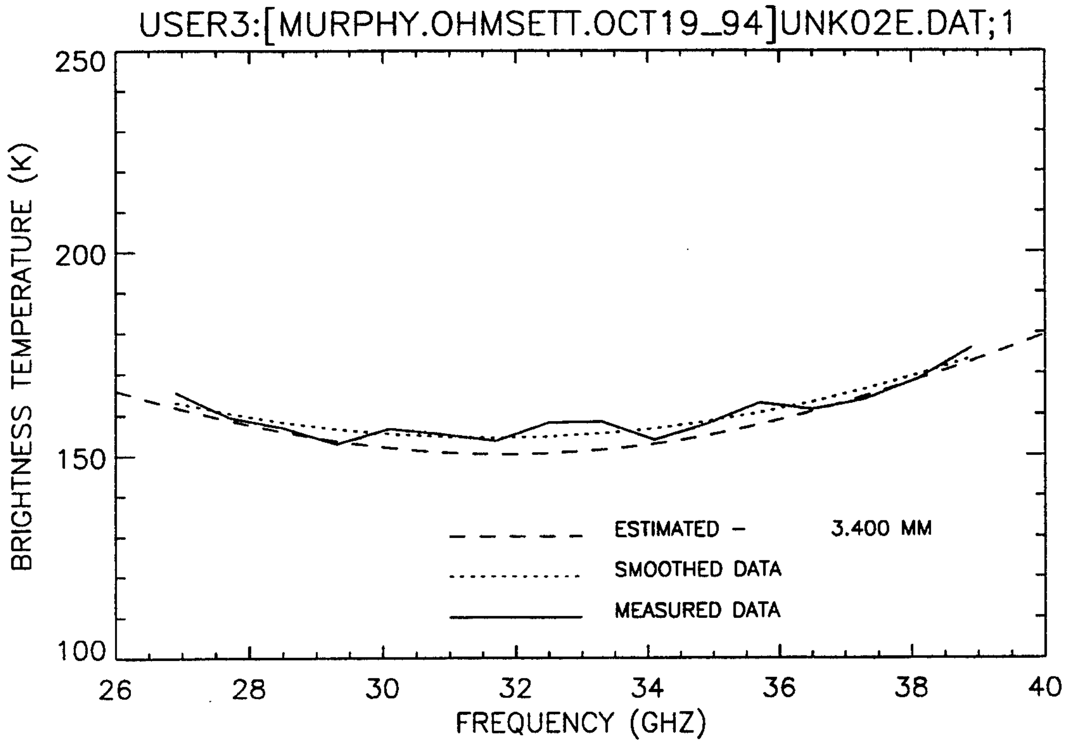

Figure G-15 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, 19 October 1994, Pass 5

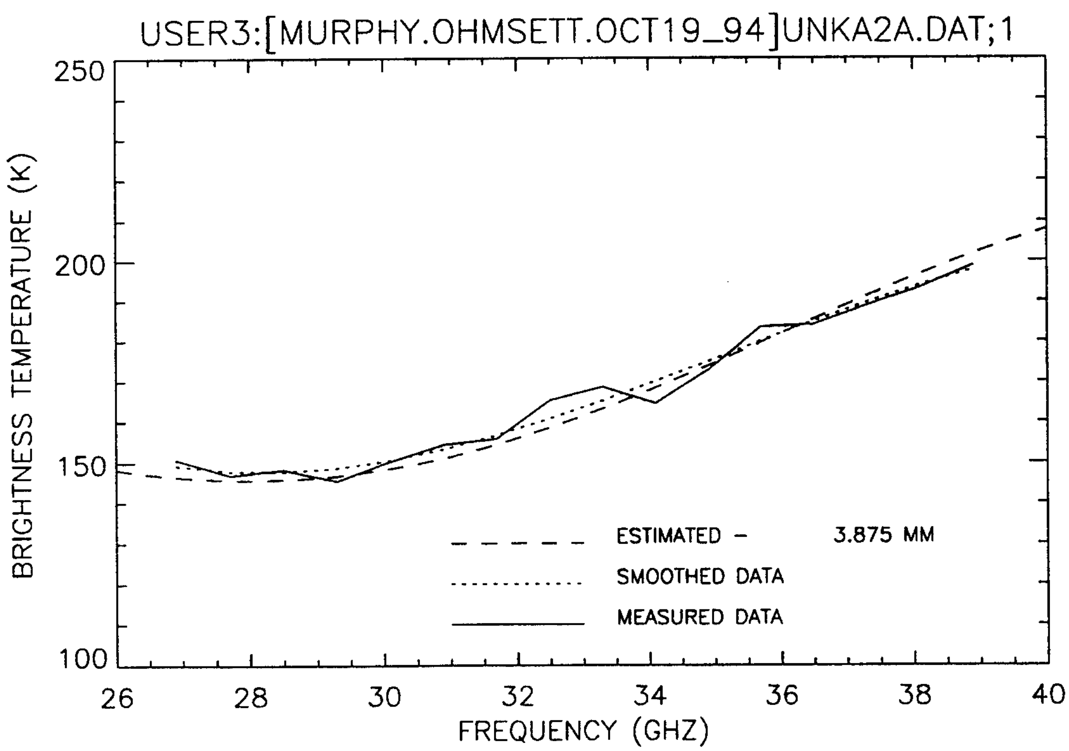

Figure G-16 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, 19 October 1994, Pass 6

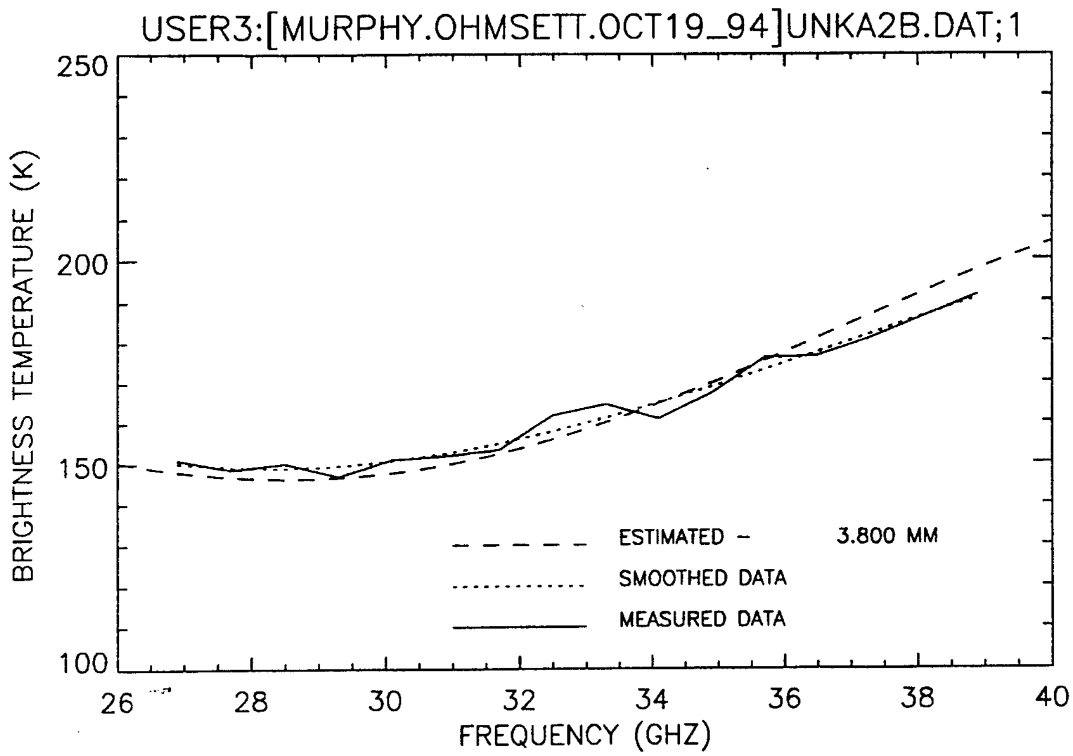

Figure G-17 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, 19 October 1994, Pass 7

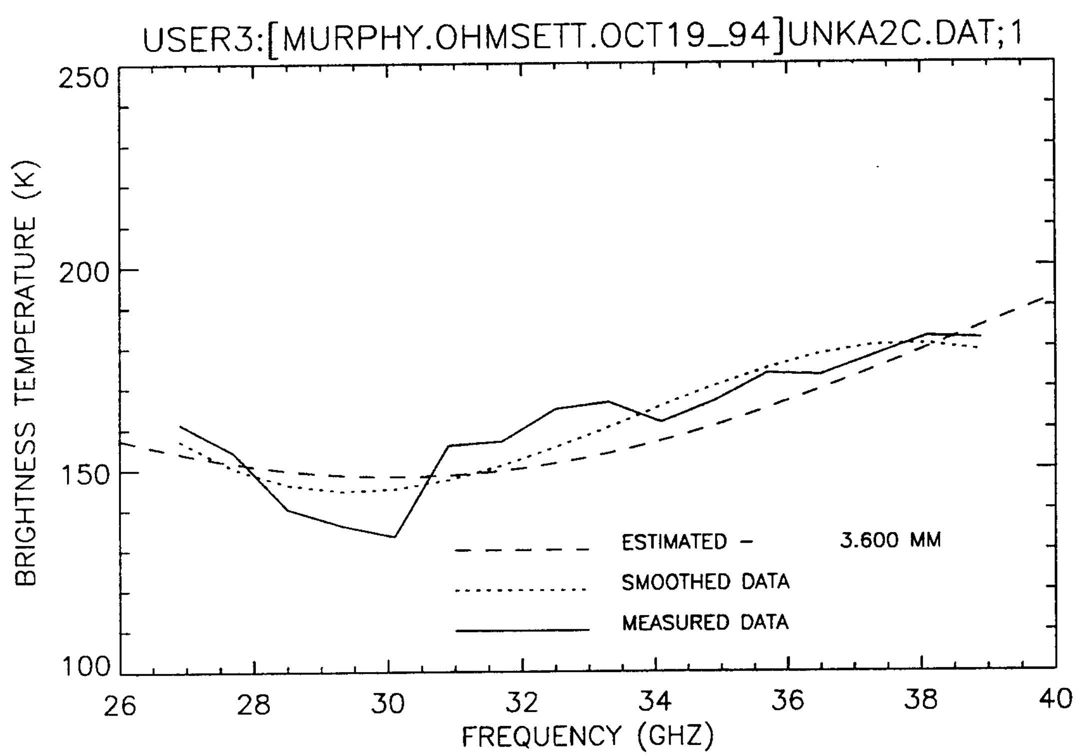

Figure G-18 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, 19 October 1994, Pass 8

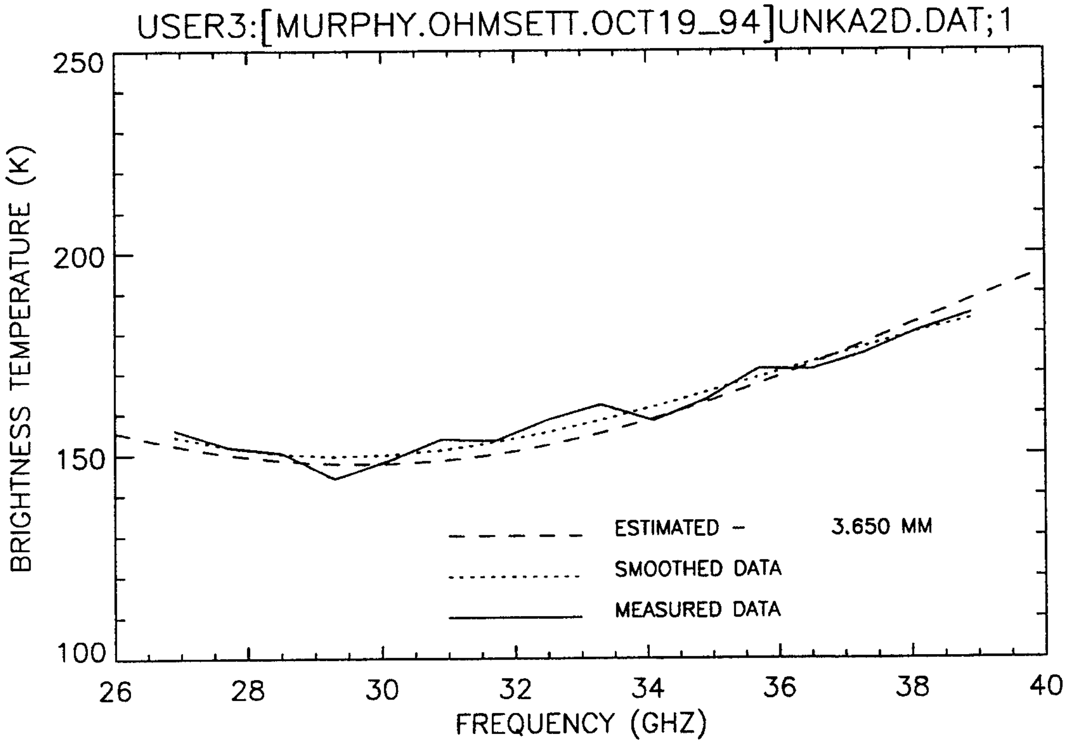

Figure G-19 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, 19 October 1994, Pass 9

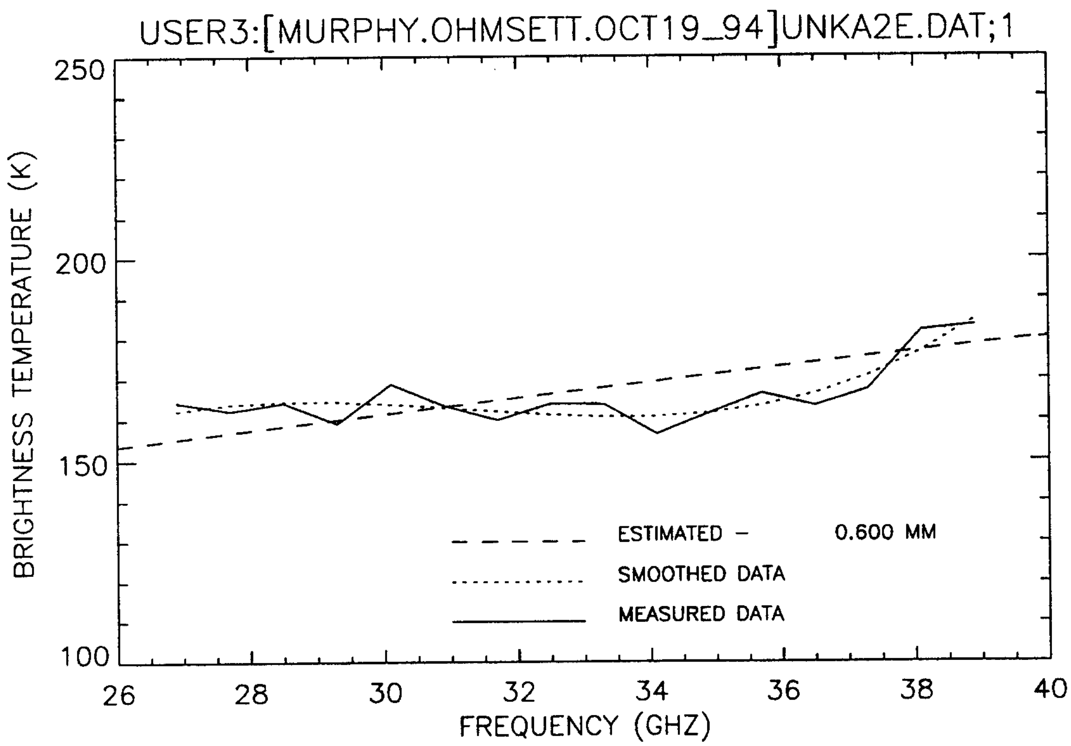

Figure G-20 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, 19 October 1994, Pass 10

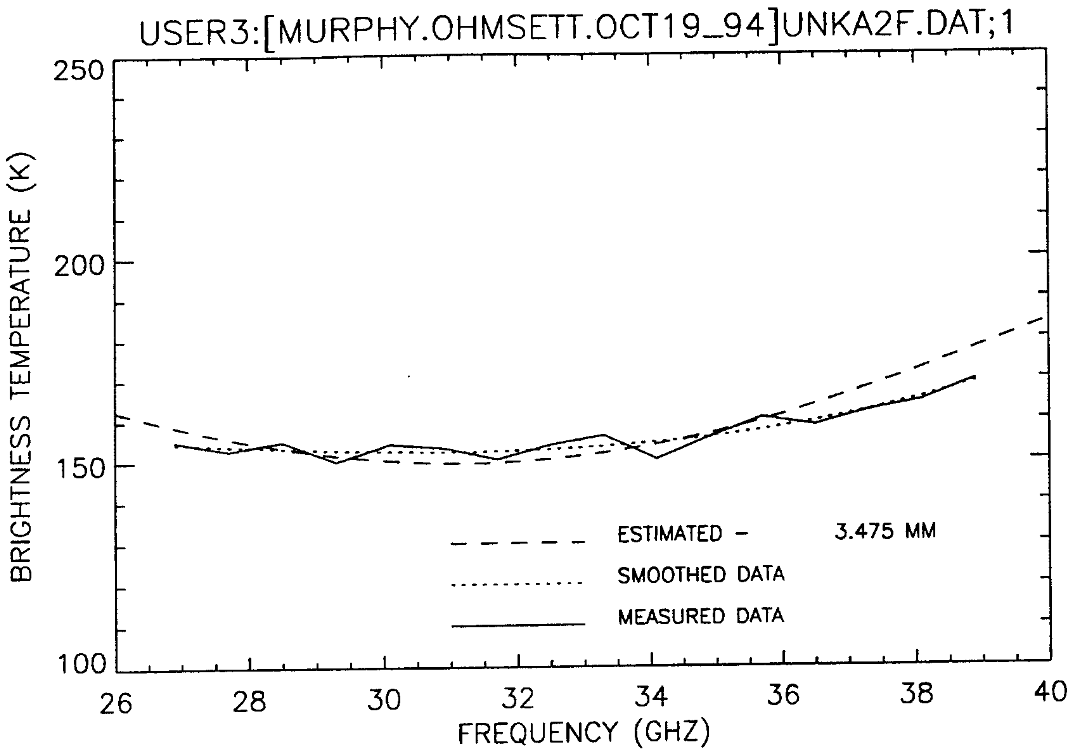

Figure G-21 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, 19 October 1994, Pass 11

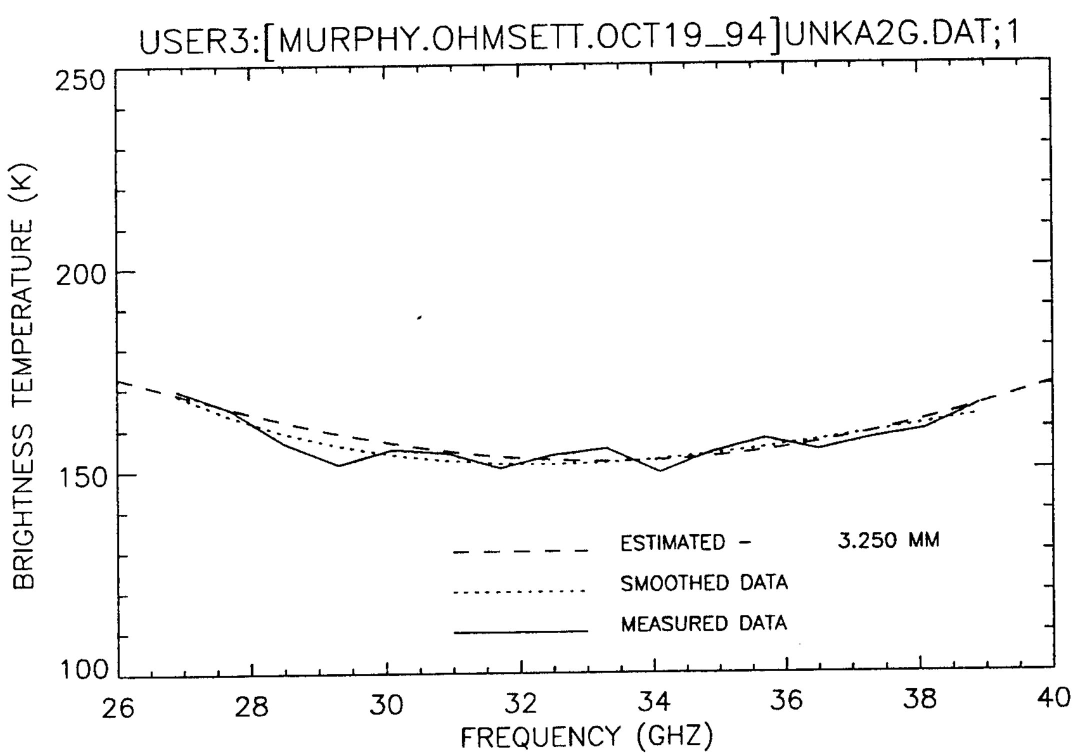

Figure G-22 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, 19 October 1994, Pass 12

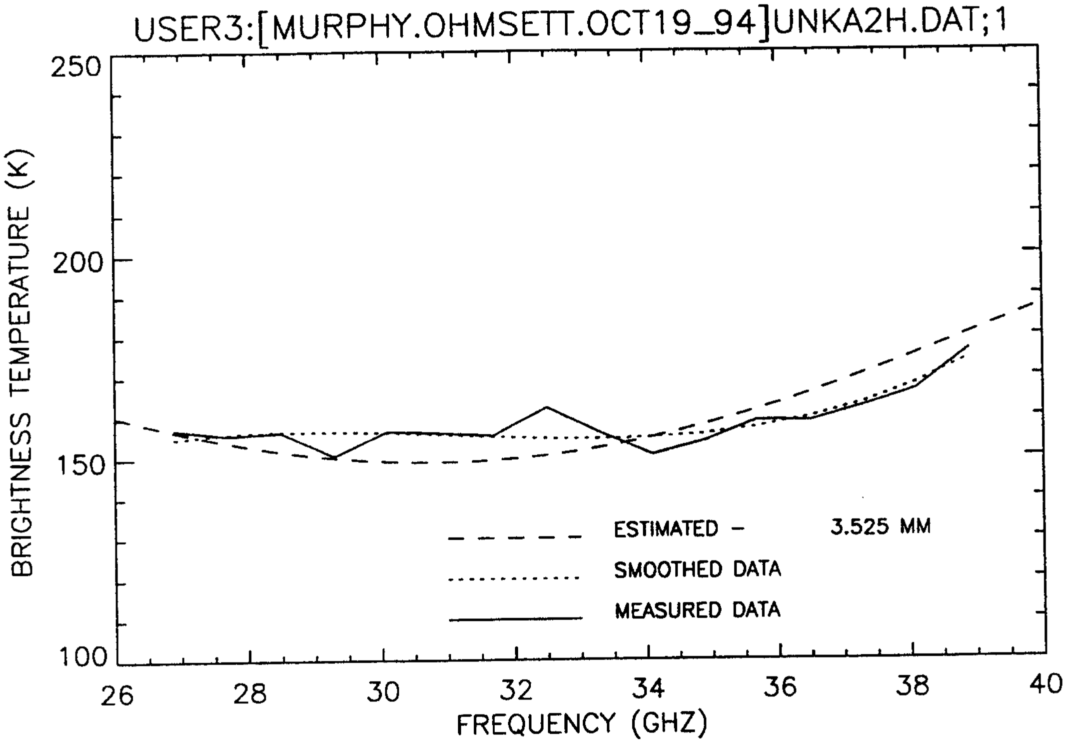

Figure G-23 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, 19 October 1994, Pass 13

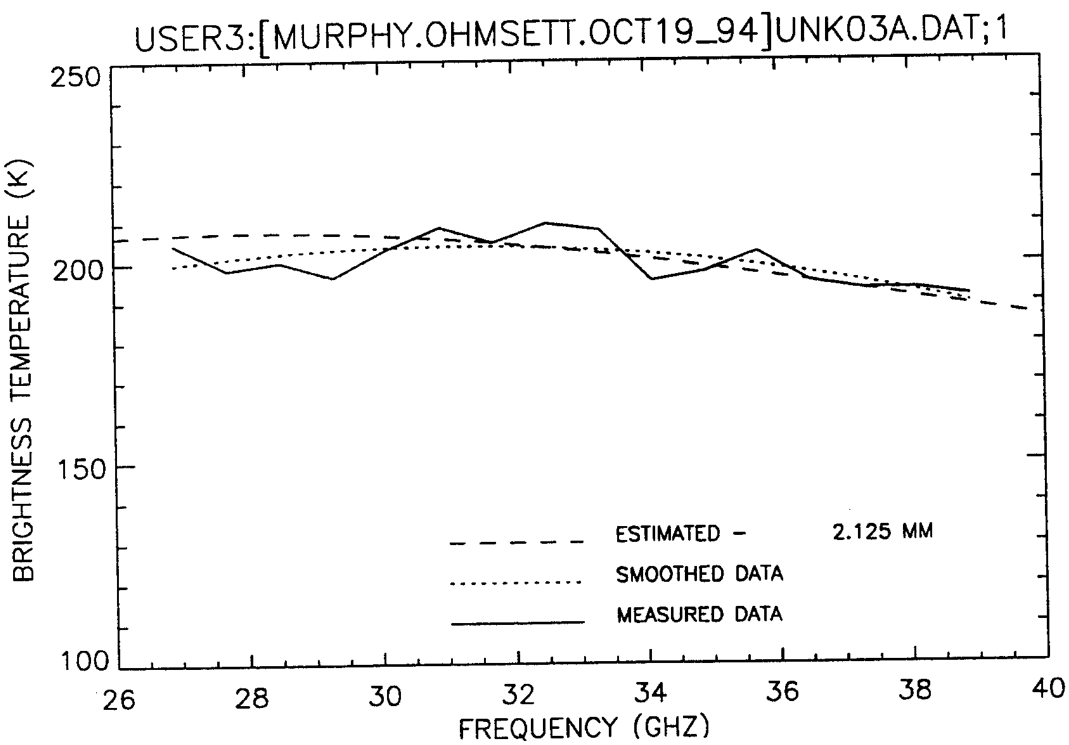

Figure G-24 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, 19 October 1994, Pass 1

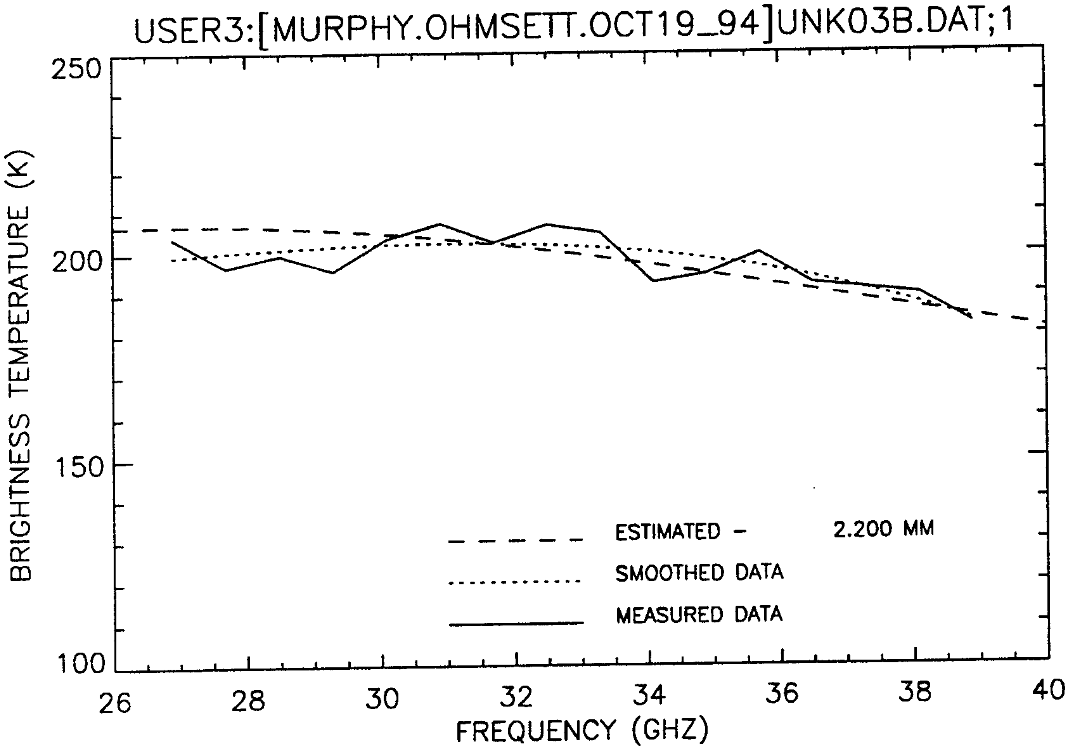

Figure G-25 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, 19 October 1994, Pass 2

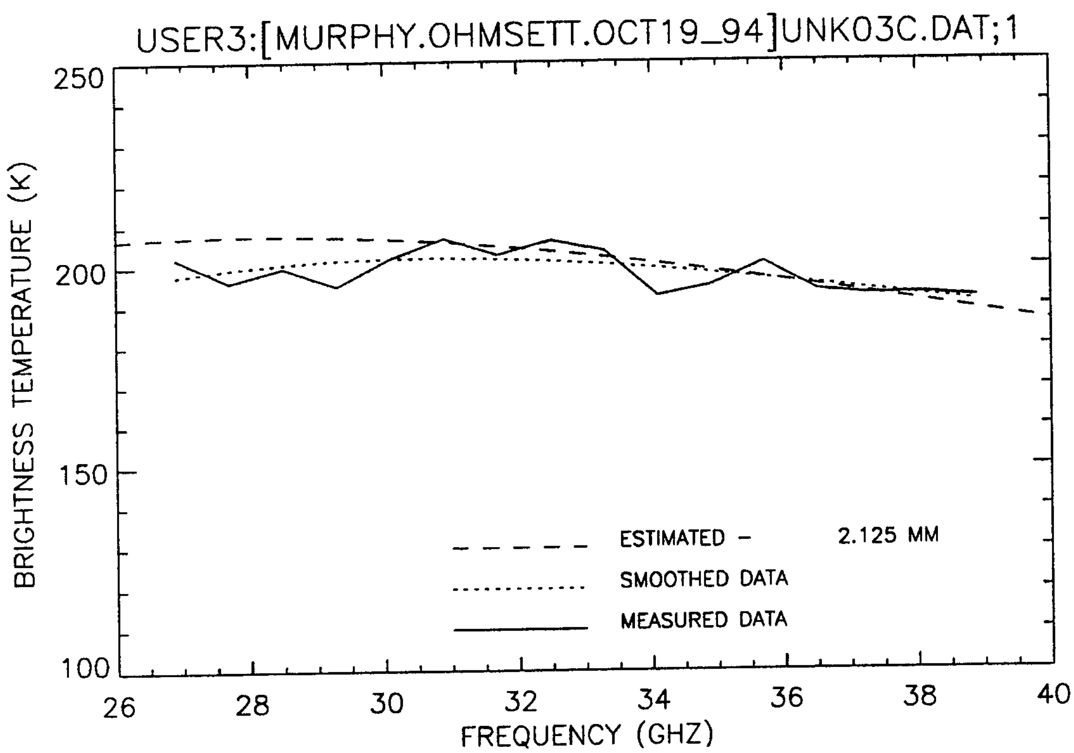

Figure G-26 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, 19 October 1994, Pass 3

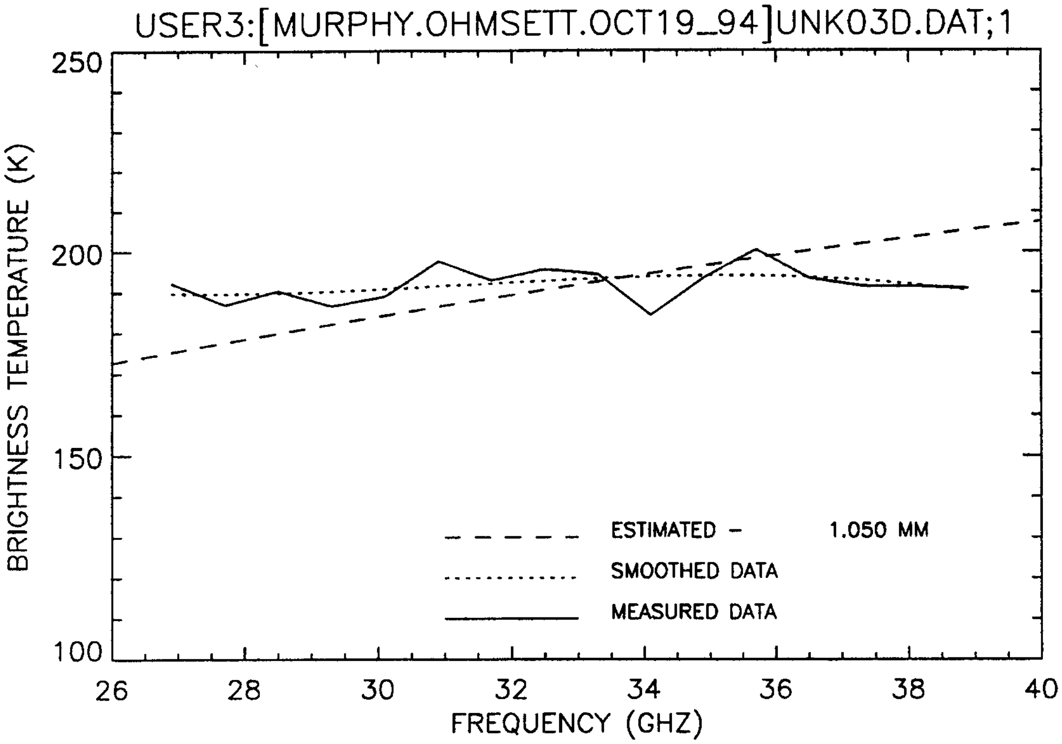

Figure G-27 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, 19 October 1994, Pass 4

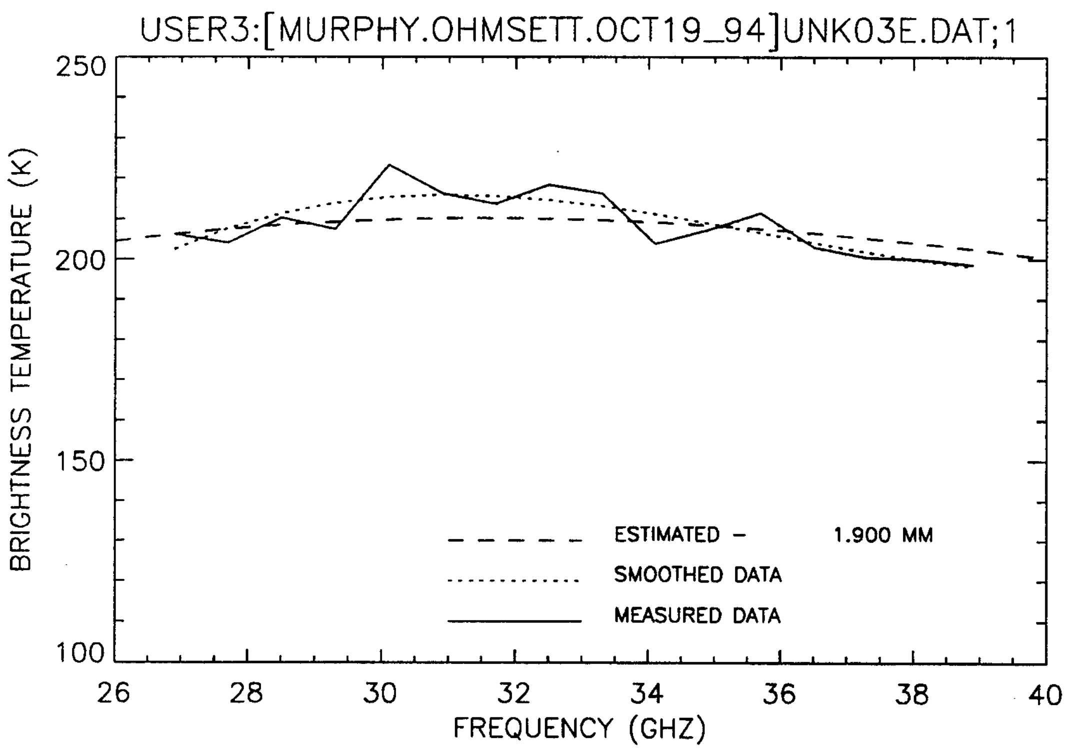

Figure G-28 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, 19 October 1994, Pass 5

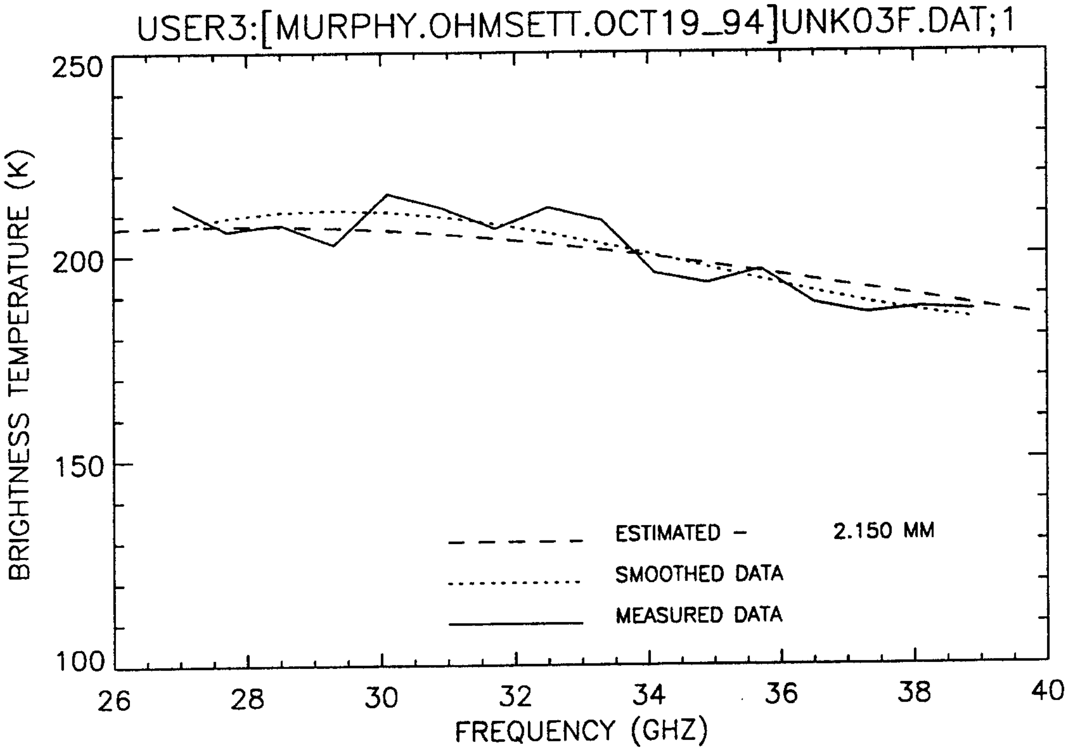

Figure G-29 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, 19 October 1994, Pass 6

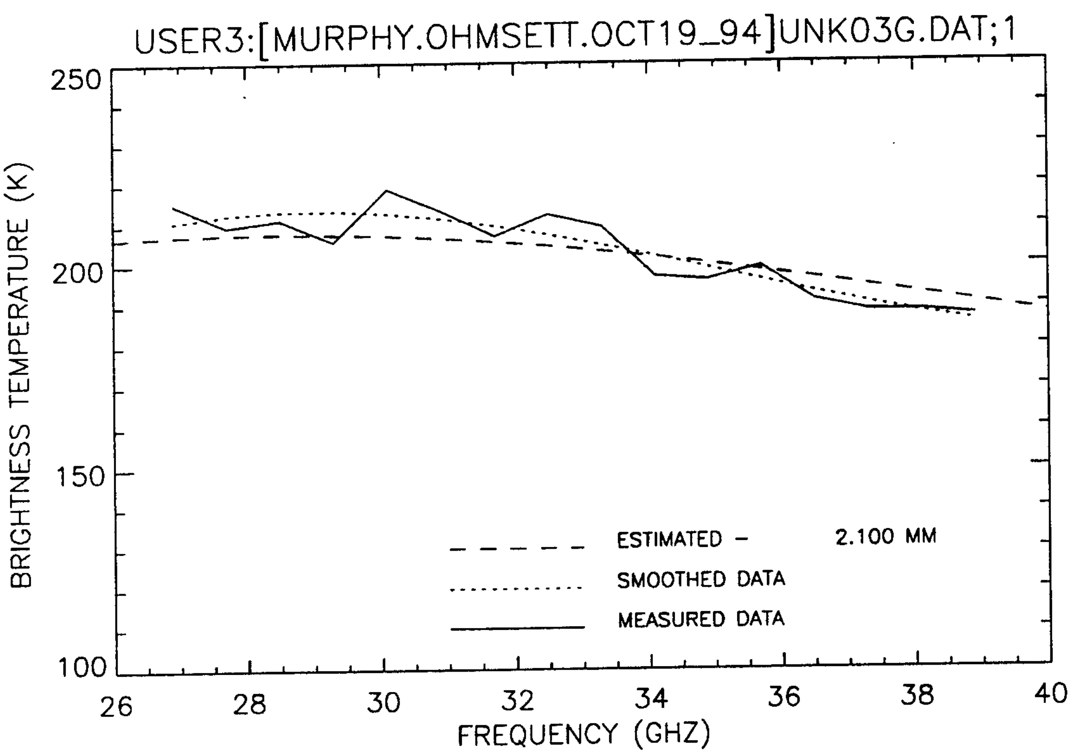

Figure G-30 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, 19 October 1994, Pass 7

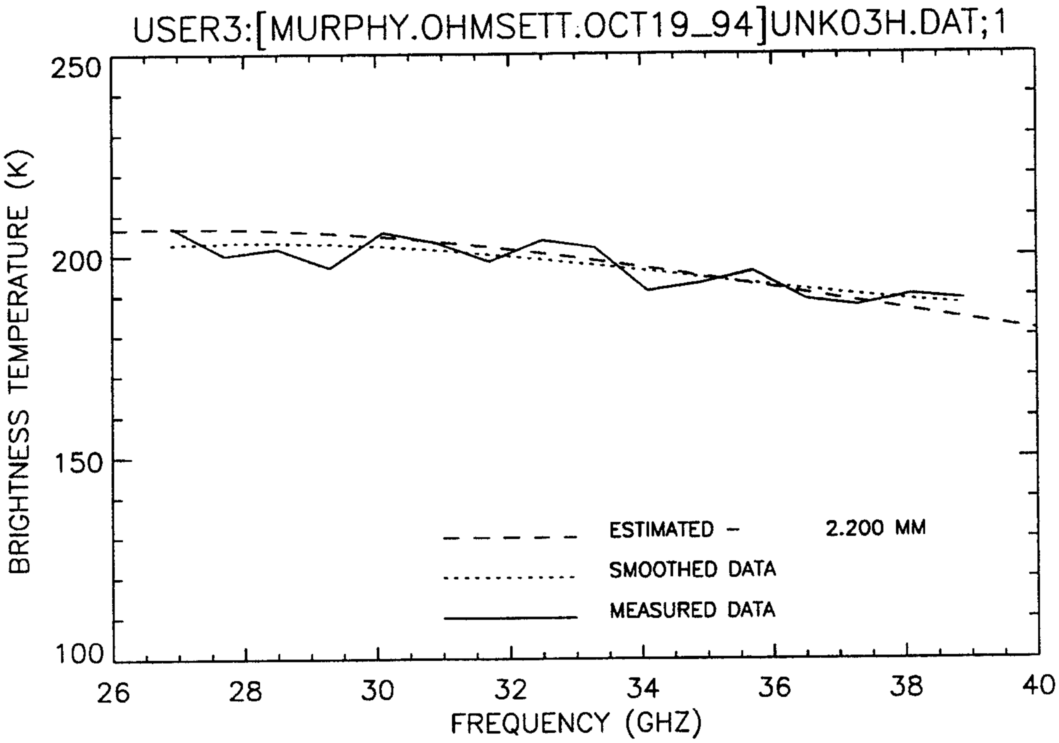

Figure G-31 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, 19 October 1994, Pass 8

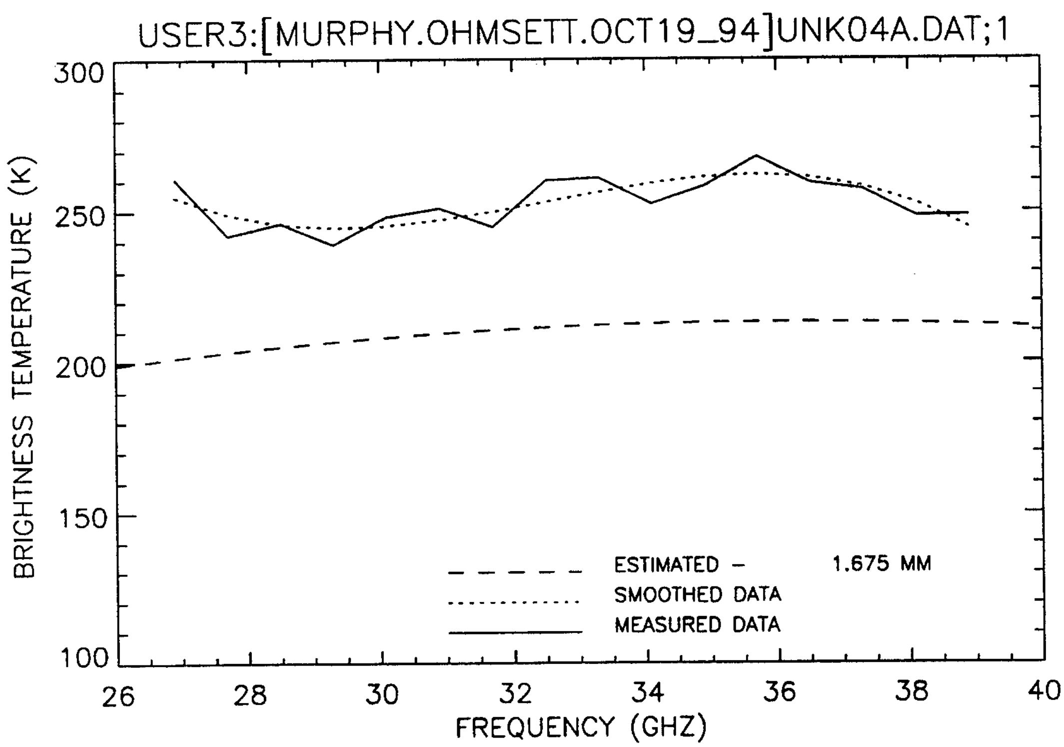

Figure G-32 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, 19 October 1994, Pass 1

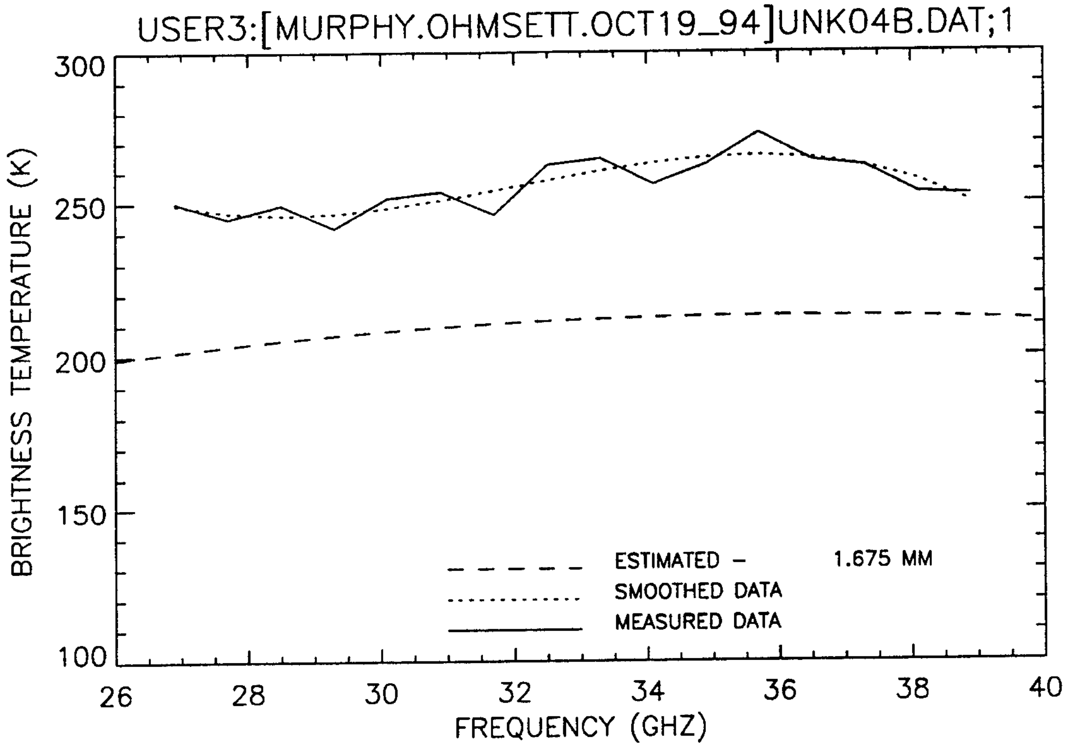

Figure G-33 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, 19 October 1994, Pass 2

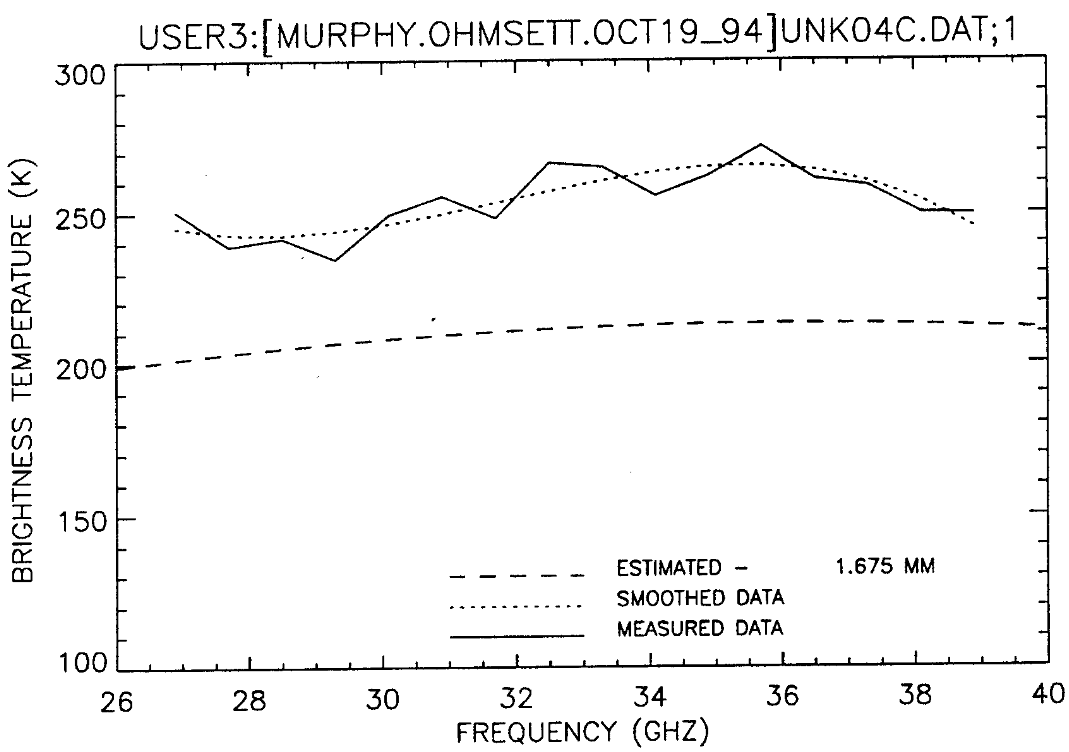

Figure G-34 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, 19 October 1994, Pass 3

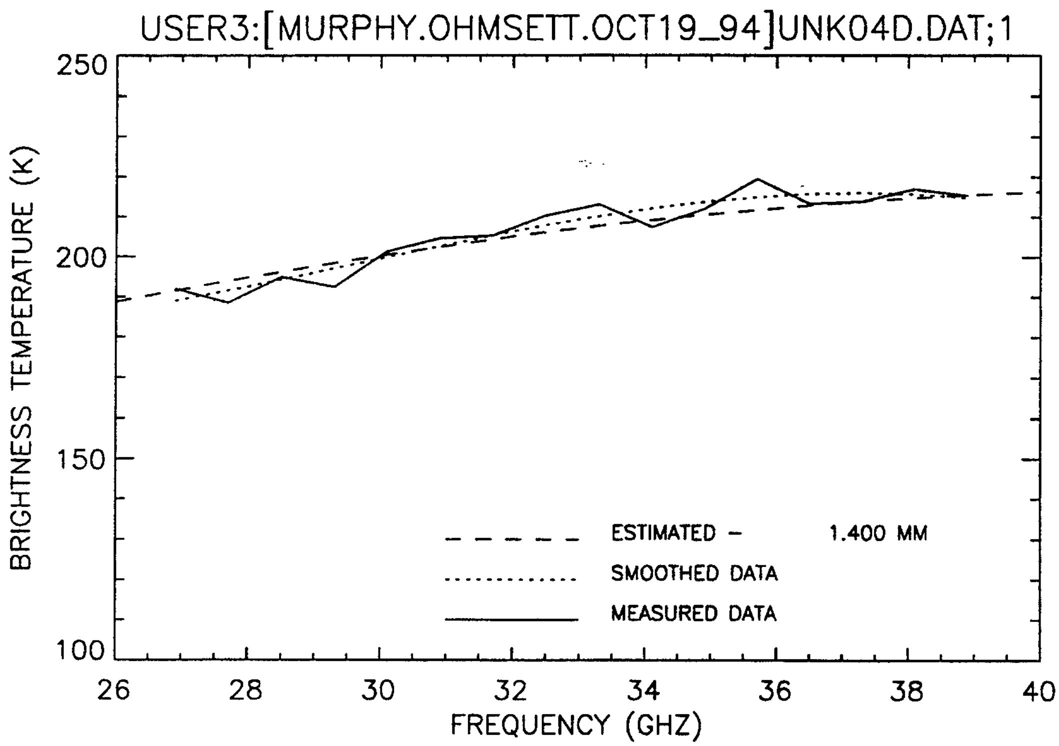

Figure G-35 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, 19 October 1994, Pass 4

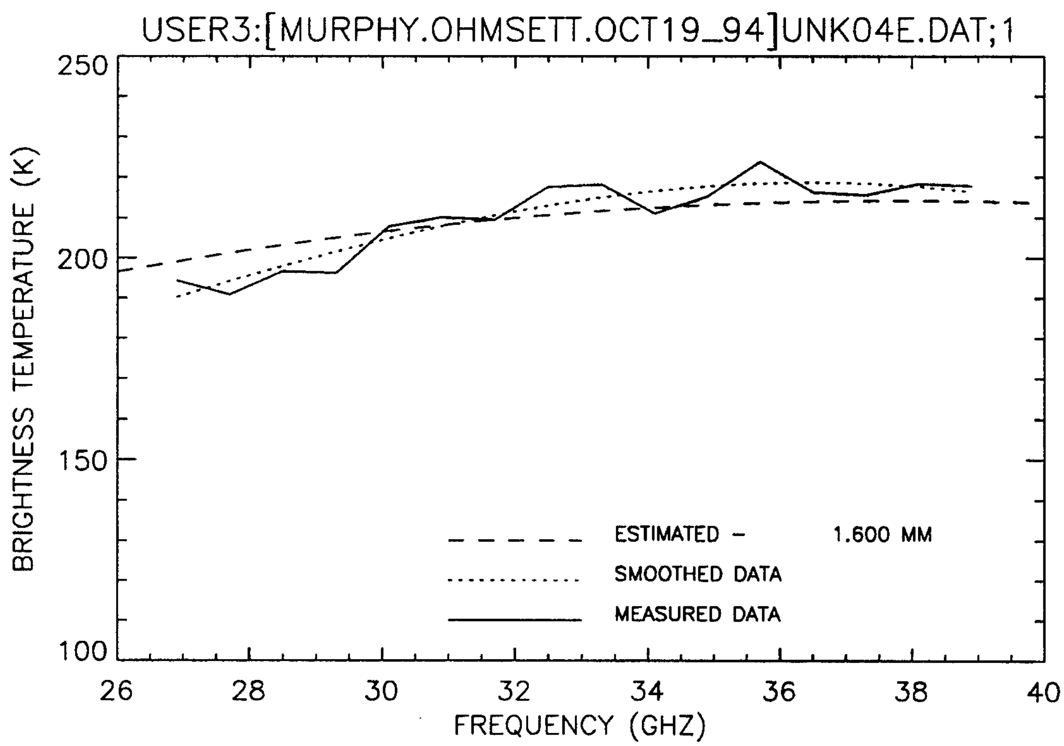

Figure G-36 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, 19 October 1994, Pass 5

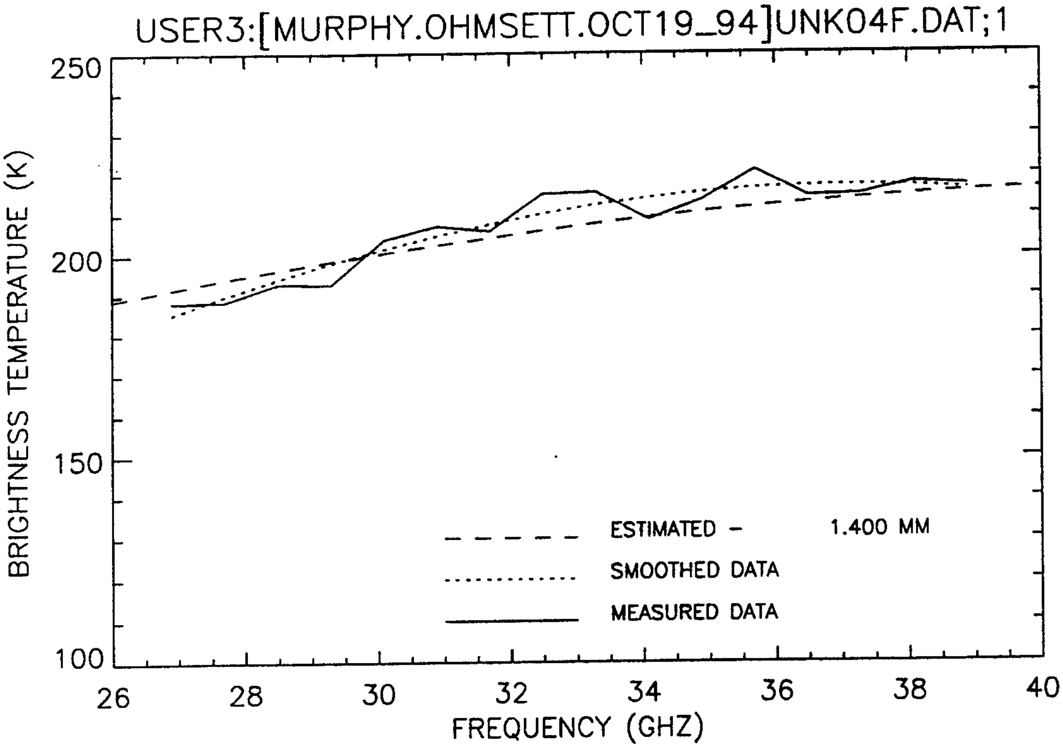

Figure G-37 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, 19 October 1994, Pass 6

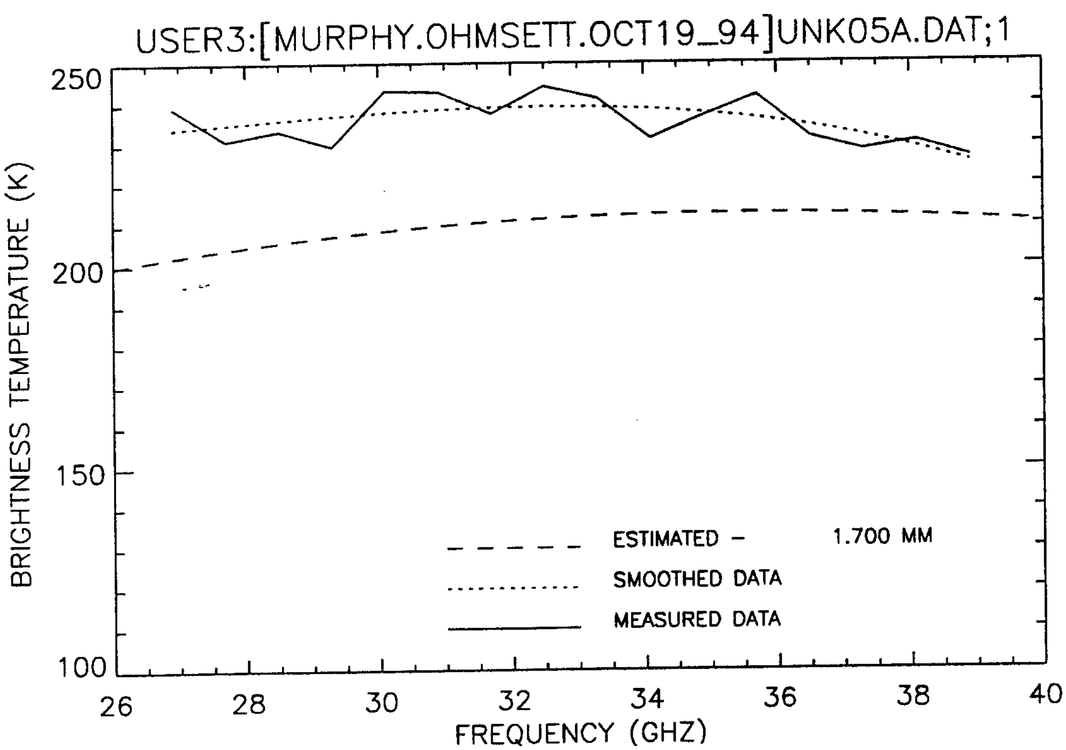

Figure G-38 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, 19 October 1994, Pass 1

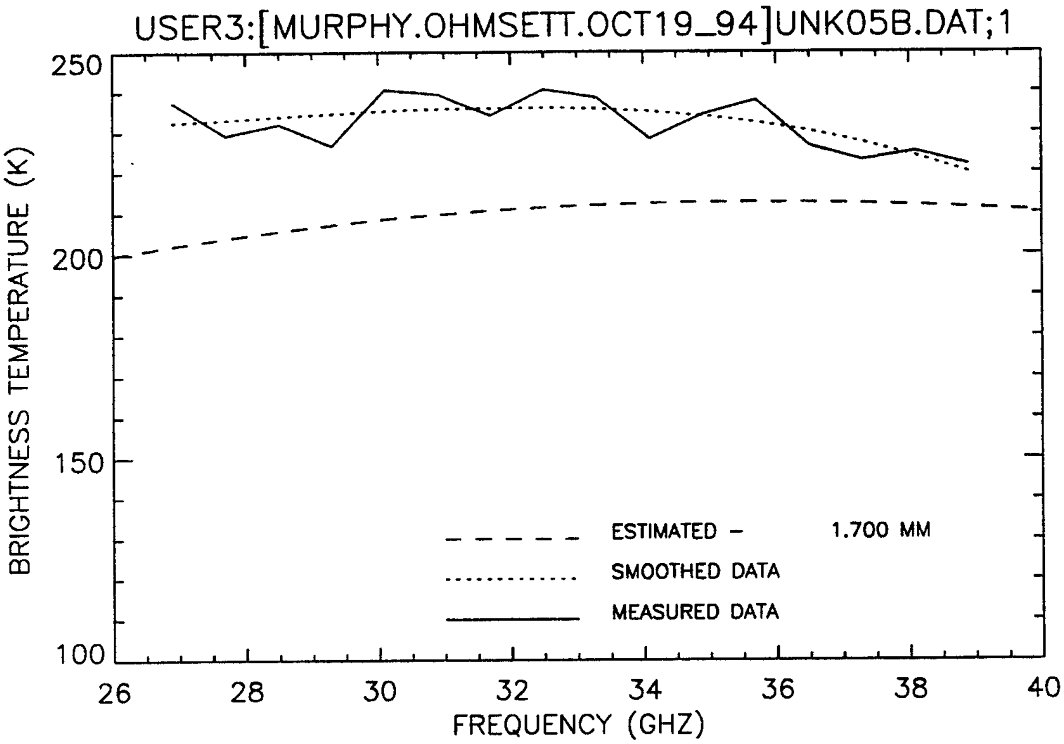

Figure G-39 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, 19 October 1994, Pass 2

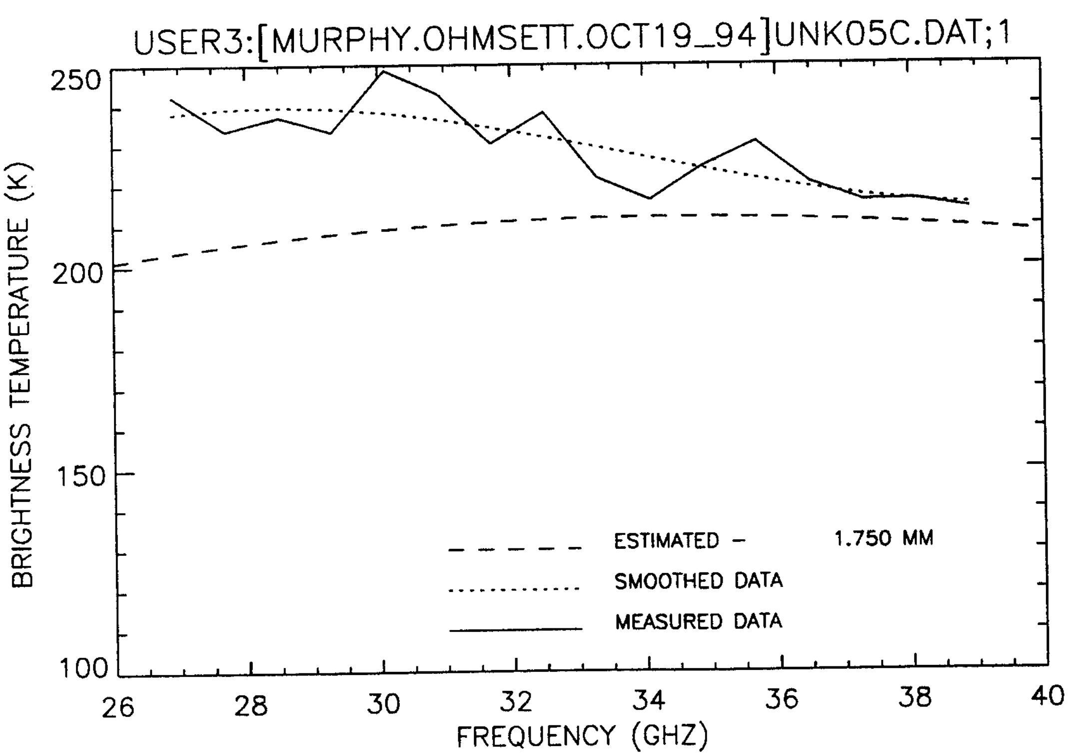

Figure G-40 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, 19 October 1994, Pass 3

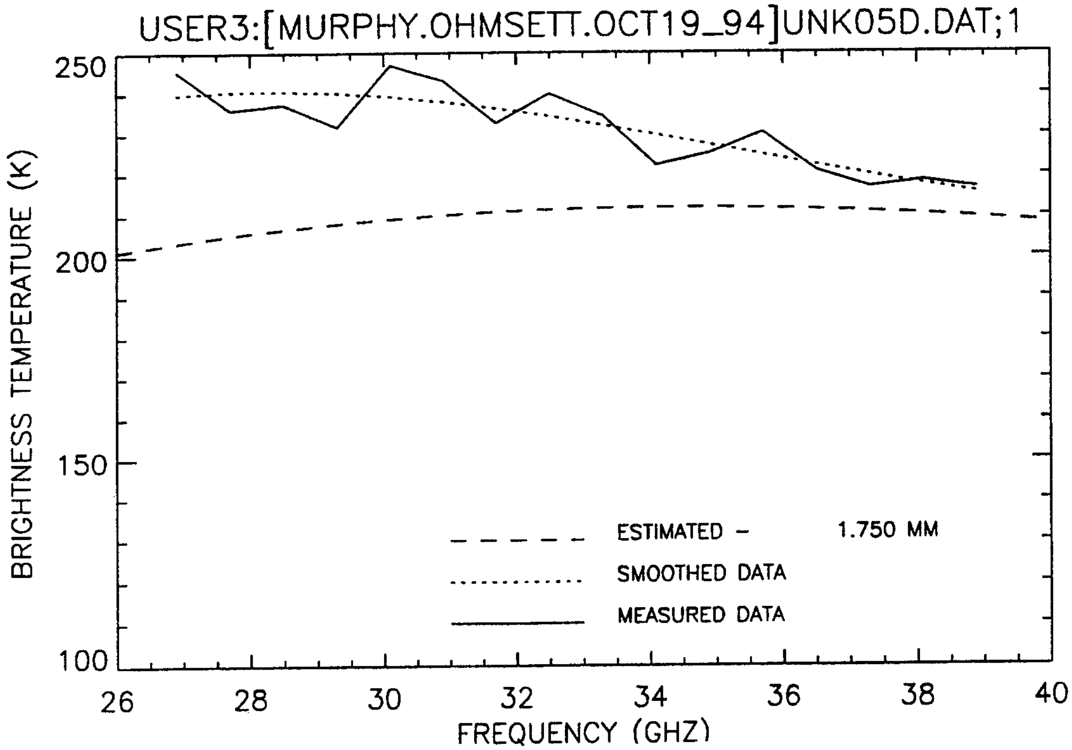

Figure G-41 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, 19 October 1994, Pass 4

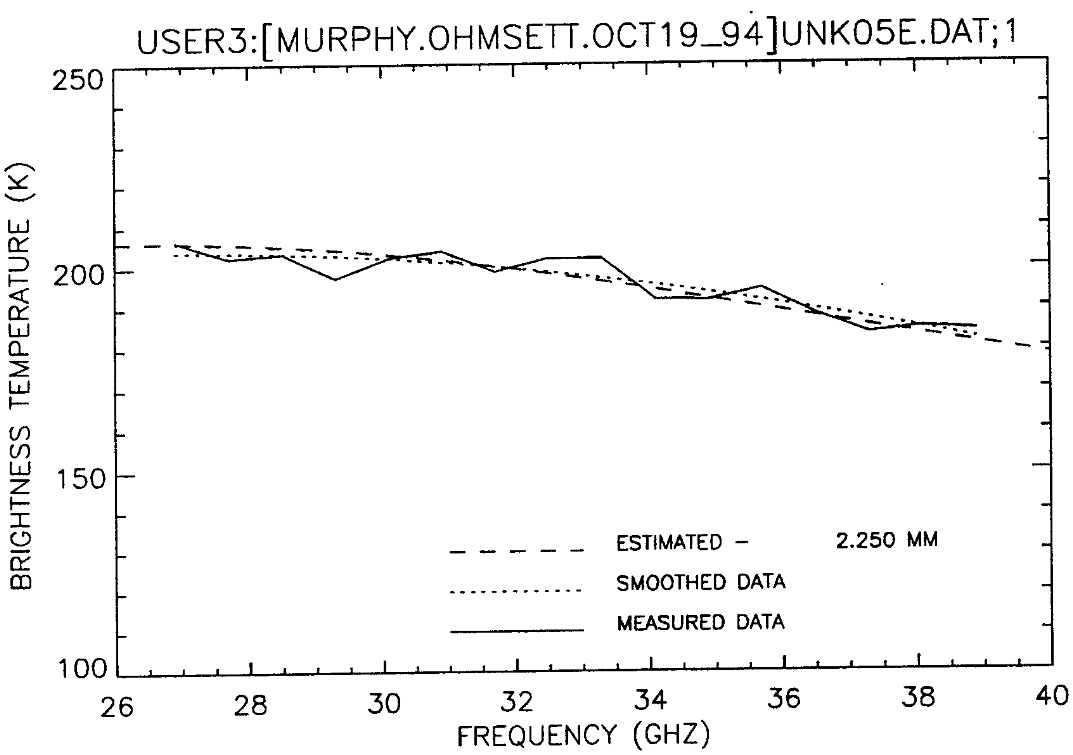

Figure G-42 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, 19 October 1994, Pass 5

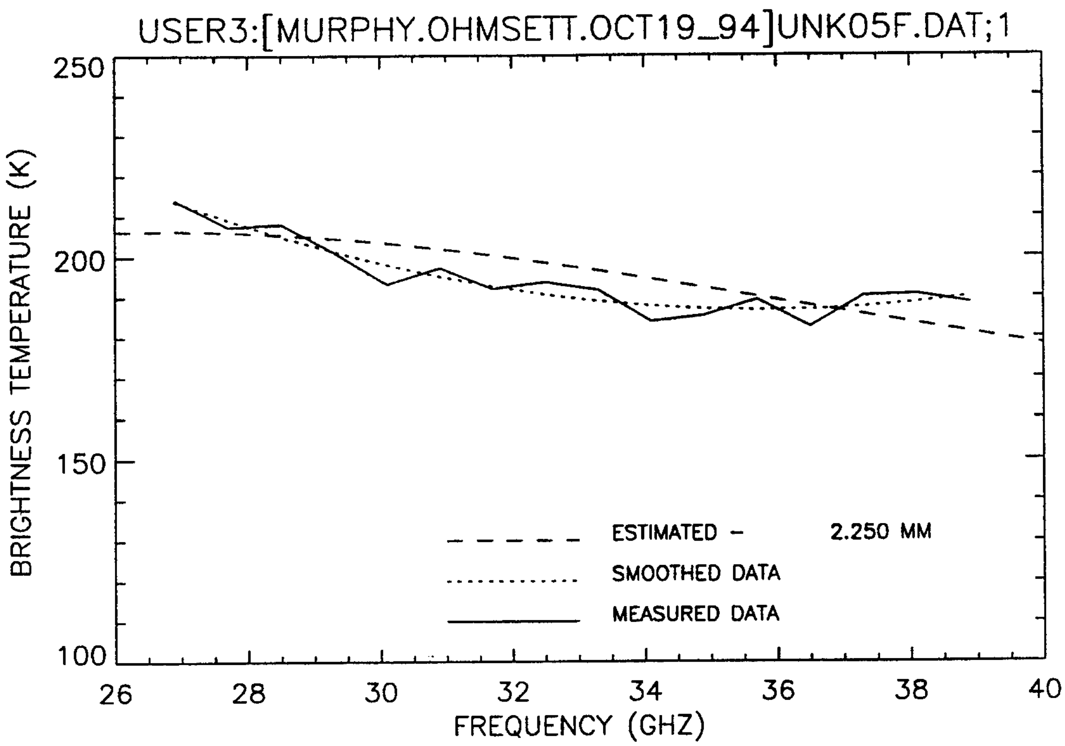

Figure G-43 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, 19 October 1994, Pass 6

The wave generator was set to create wave condition 1. Data collection commenced after the waves had achieved a steady-state condition,. The water in the "clean" water target visually appeared to have some contamination on its surface. The following water measurements were collected between the water target (pool 6) and the most southern oil target (pool 5) because the water here appeared cleaner than the water in pool 6.

UNKW1A - This curve was chosen as the background water reference for this set of measurements.

UNKW1B - This curve is a fair match to the algorithm estimate of 0.000 mm. The measured data curve seems to have a slightly steeper slope than the theoretical prediction.

UNKW1C - This curve is a fair match to the algorithm estimate of 0.000 mm. The measured data curve seems to have a slightly steeper slope than the theoretical prediction.

The main bridge was moved over target pool 1. This target consisted of 0.74 mm of diesel oil that covered 90% of the surface in the containment area. The following measurements are from the south end of the pool. The oil thickness in this half of the pool appeared thicker than in the north side.

UNKWXA - This curve is a fair match to the algorithm estimate of 0.900 mm. The measured data curve seems to have a slightly steeper slope than the theoretical prediction.

UNKWXB - This curve is a good-to-excellent match to the algorithm estimate of 0.975 mm.

UNKWXC - This curve is a fair match to the algorithm estimate of 0.925 mm. The measured data curve seems to have a slightly steeper slope than the theoretical prediction.

The main bridge was moved to collect measurements from the north end of oil target pool 1.

UNKWXD - This curve is a fair-to-good match to the algorithm estimate of 0.275 mm.

UNKWXE - This curve is a fair-to-good match to the algorithm estimate of 0.375 mm.

UNKWXF - This curve is a fair-to-good match to the algorithm estimate of 0.550 mm.

The following measurements were collected from the center of oil target pool 2. This target consisted of 2.6 mm of diesel oil that covered 100% of the containment area.

UNKW2A - This curve is an excellent match to the algorithm estimate of 3.525 mm.

UNKW2B - This curve is a poor match to the algorithm estimate of 0.400 mm. The measured data points agree well a theoretical prediction of 3.7 mm from 26 GHz to 36 GHz, but then the measured curve seems to fall off from the estimate.

UNKW2C - This curve is a fair match to the algorithm estimate of 3.475 mm. The measured T^B points are overall slightly higher in temperature than the estimated curve predicts; however, the shape of the measured data curve seems to be a very good match to the data points.

The following measurement from oil pool 3 were collected from the center of the oil target. The target consisted of a 2.0 mm thickness of a mixture of 75% diesel oil and 25% crude oil that covered 100% of the containment area.

UNKW3A - This curve is a fair-to-good match to the algorithm estimate of 1.950 mm. This measurement was very noisy.

UNKW3B - This curve is a poor match to the algorithm estimate of 1.900 mm. The T^B of the measured data points seem slightly higher than the estimate predicts; this may indicate an emulsion. However based on the other two measurements, a 2.0 mm estimate is appropriate.

UNKW3C - This curve is an excellent match to the algorithm estimate of 2.000 mm.

The following measurements were collected over the south end of target pool 4. This target was a 1.7 mm thickness of a mixture of 50% diesel oil and 50% waste

oil, covering approximately 60% of the containment area. There is approximately 60% antenna beam fill.

UNKW4A - This curve is a poor match to the algorithm estimate of 1.300 mm. A 1.7 mm estimate seems more appropriate even though the overall T^B is a bit low. Using the 1.7 mm estimate and an antenna beam fill of 85% (plotted) resulted in an excellent match.

UNKW4B - This curve is a poor match to the algorithm estimate of 1.175 mm. A 1.7 mm estimate seems more appropriate, but in this case the overall T^B is too low. Using the 1.7 mm estimate and an antenna beam fill of 80% (plotted) resulted in an excellent match.

UNKW4C - This curve is a poor match to the algorithm estimate of 1.275 mm. A 1.7 mm estimate seems more appropriate, but in this case again the overall T^B is a bit too low. Using the 1.7 mm estimate and an antenna beam fill of 80% (plotted) resulted in an excellent match.

The following measurement are from the "swirly" oil coverage area.

UNKW4D - This curve is a good-to-excellent match to the algorithm estimate of 0.500 mm.

UNKW4E - This curve is a good-to-excellent match to the algorithm estimate of 0.500 mm.

The main bridge was moved over target pool 5. This target consisted of a 2.5 mm thickness of a mixture of 75% diesel oil and 25% waste oil covering 100% of the containment area. The following measurements are from the south end of the pool. This end of the pool contained a higher percentage of the brownish inclusion in the oil than the north end.

UNKW5A - This curve is a good match to the algorithm estimate of 1.825 mm, though the measured data below 30 GHz seems high.

UNKW5B - This curve is a fair match to the algorithm estimate of 1.825 mm; however, a 1.9 mm estimate provided a better match to the data above 34 GHz.

UNKW5C - This curve is a fair match to the algorithm estimate of 1.975 mm.

The main bridge was moved to collect data from the north end of target pool 5.

UNKW5D - This curve is a poor match to the algorithm estimate of 1.675 mm. The overall high T^B indicates an emulsion.

UNKW5E - This file was lost.

UNKW5F - This curve is a poor match to the algorithm estimate of 1.675 mm. The overall high T^B indicates an emulsion.

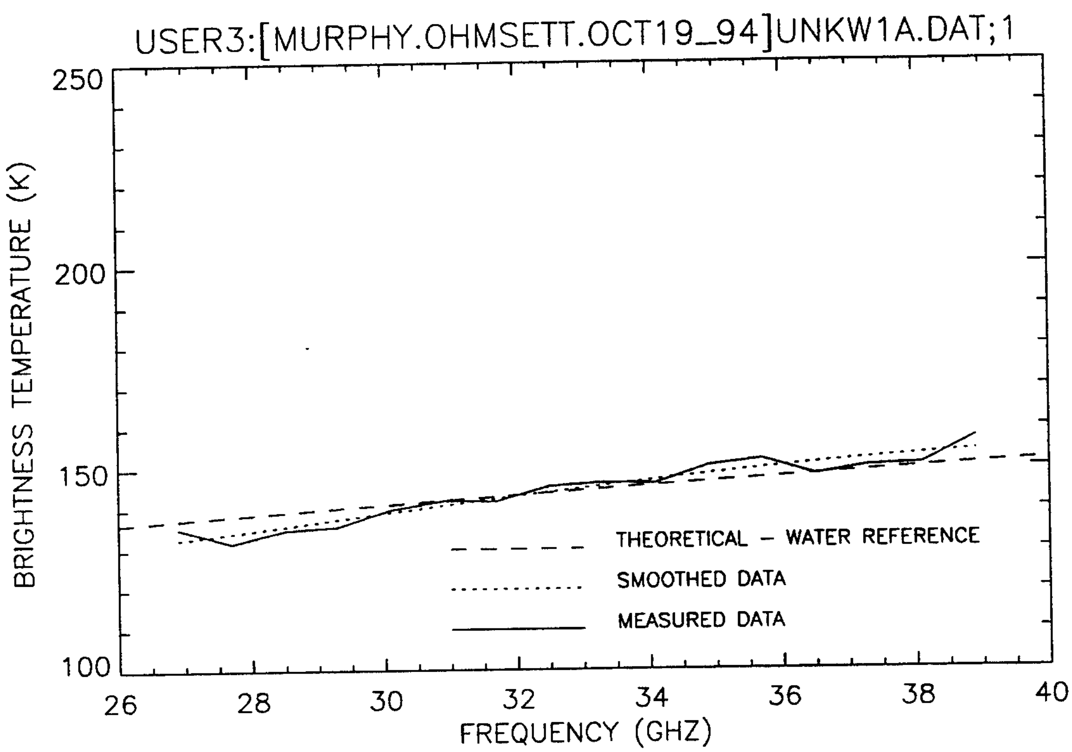

Figure G-44 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, Wave Condition 1, 19 October 1994, Pass 1

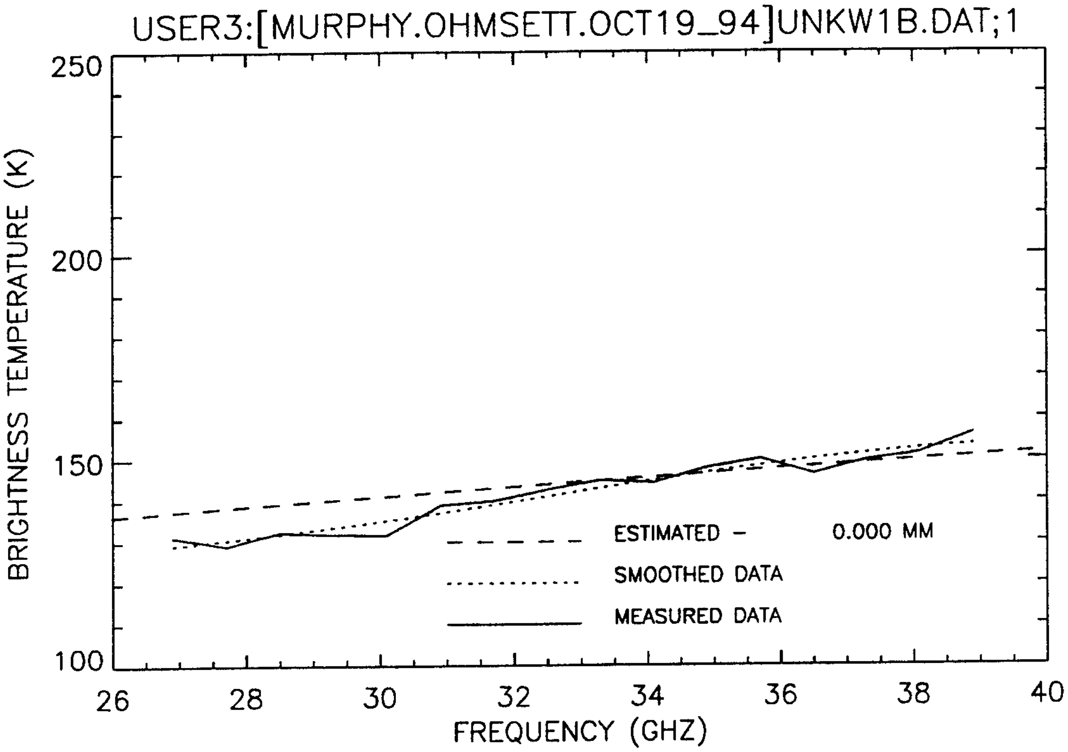

Figure G-45 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, Wave Condition 1, 19 October 1994, Pass 2

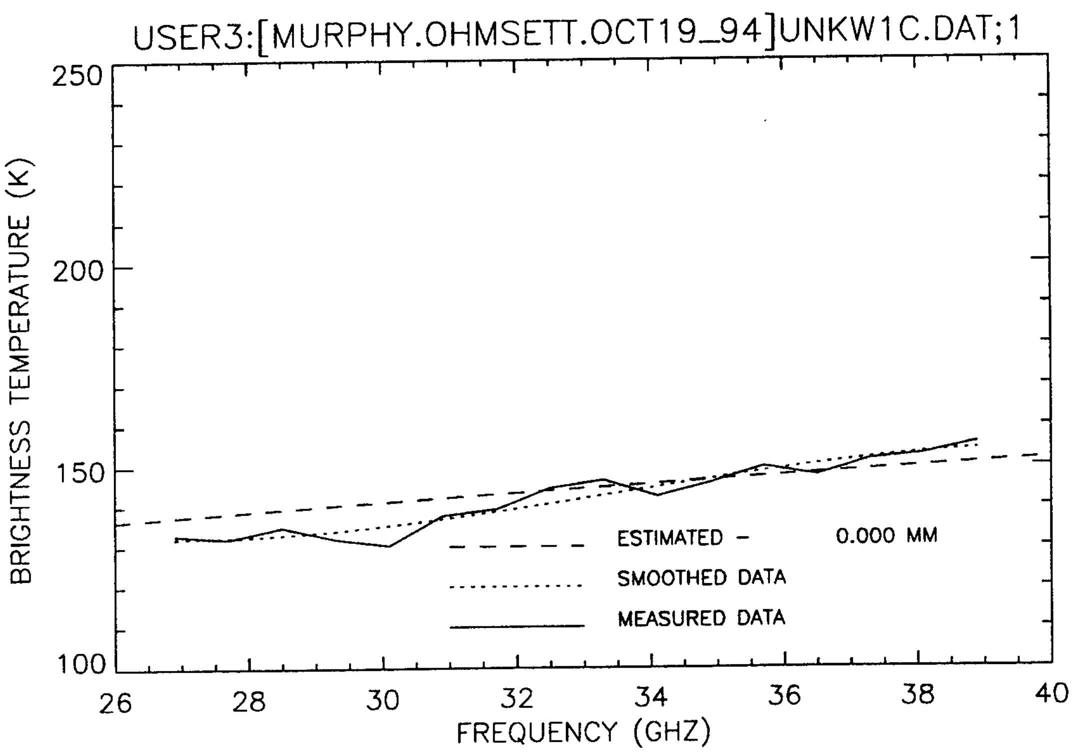

Figure G-46 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, Wave Condition 1, 19 October 1994, Pass 3

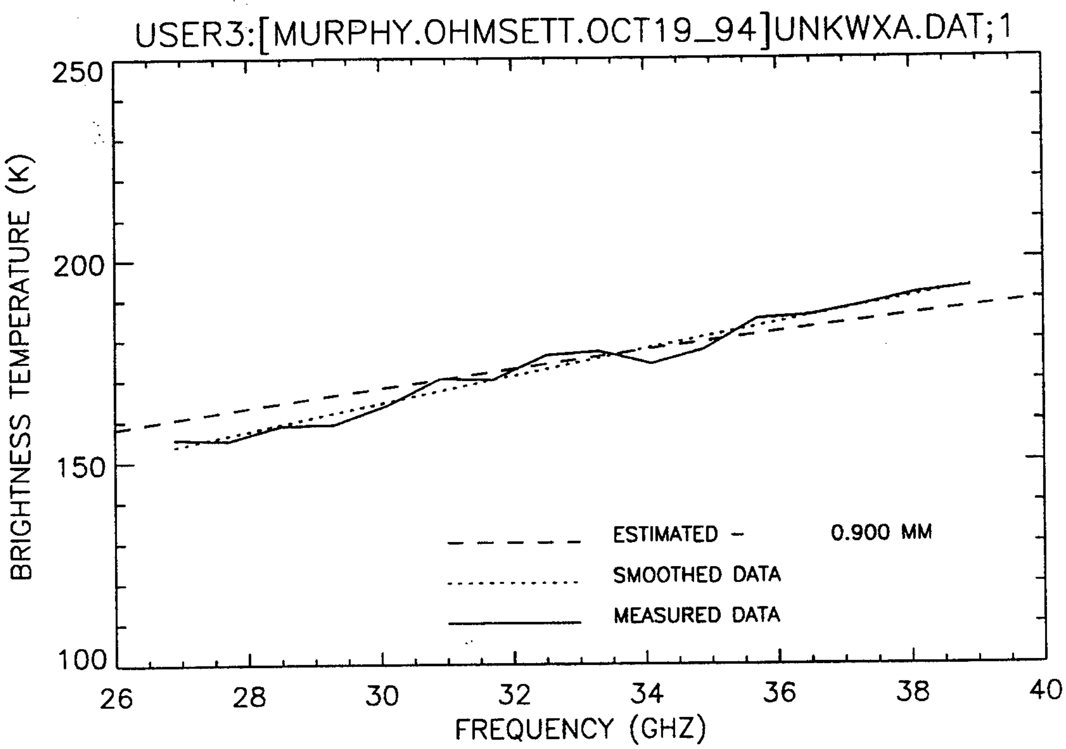

Figure G-47 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Wave Condition 1, 19 October 1994, Pass 1

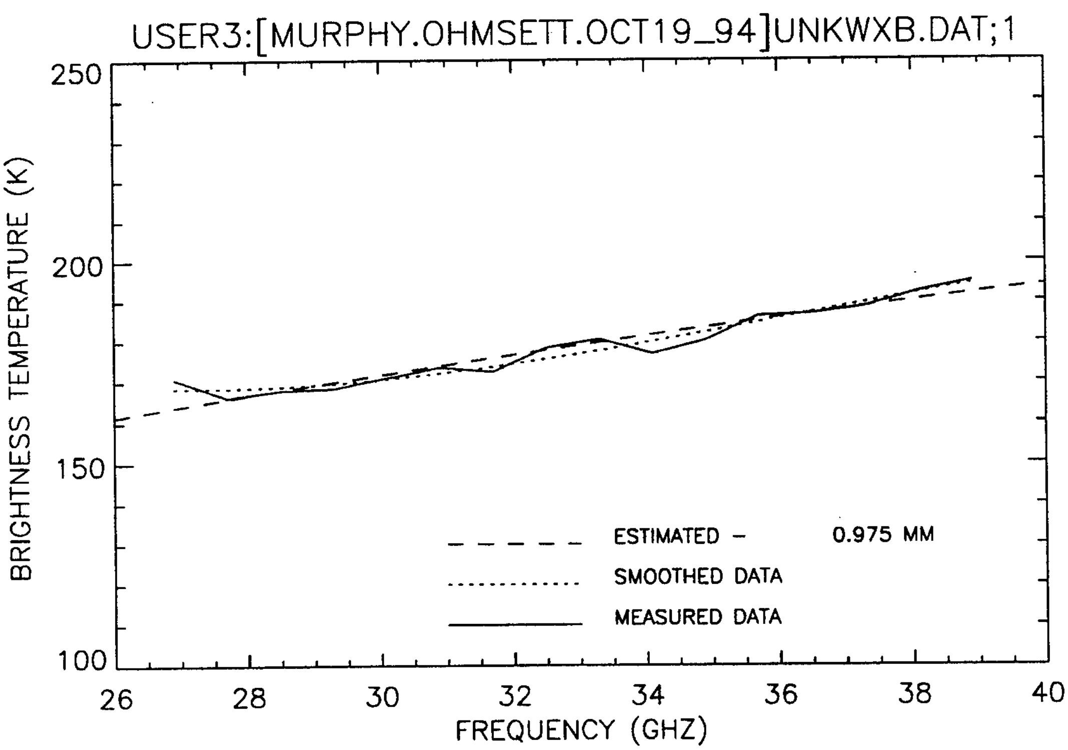

Figure G-48 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Wave Condition 1, 19 October 1994, Pass 2

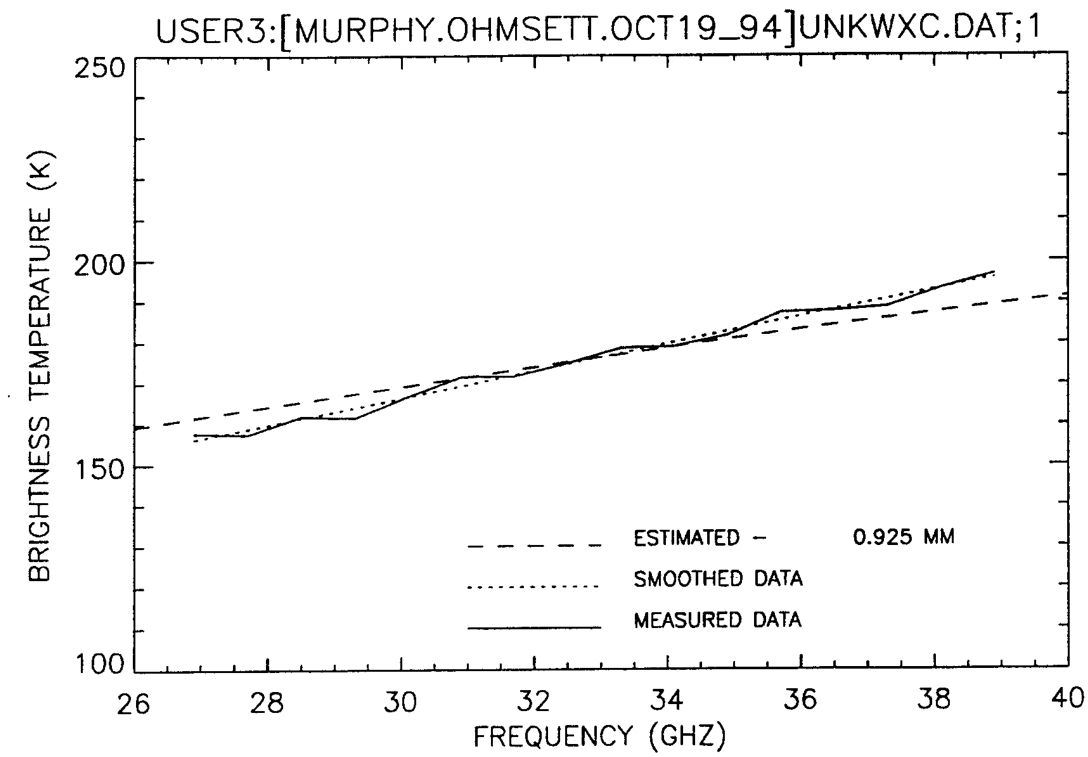

Figure G-49 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Wave Condition 1, 19 October 1994, Pass 3

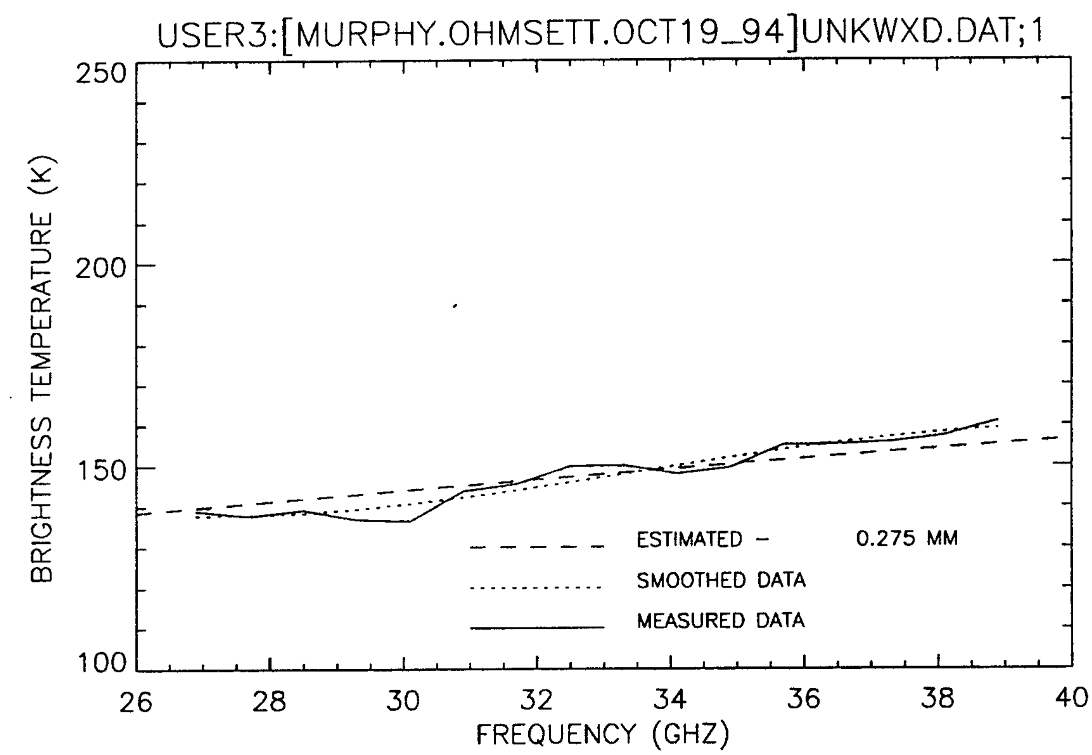

Figure G-50 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Wave Condition 1, 19 October 1994, Pass 4

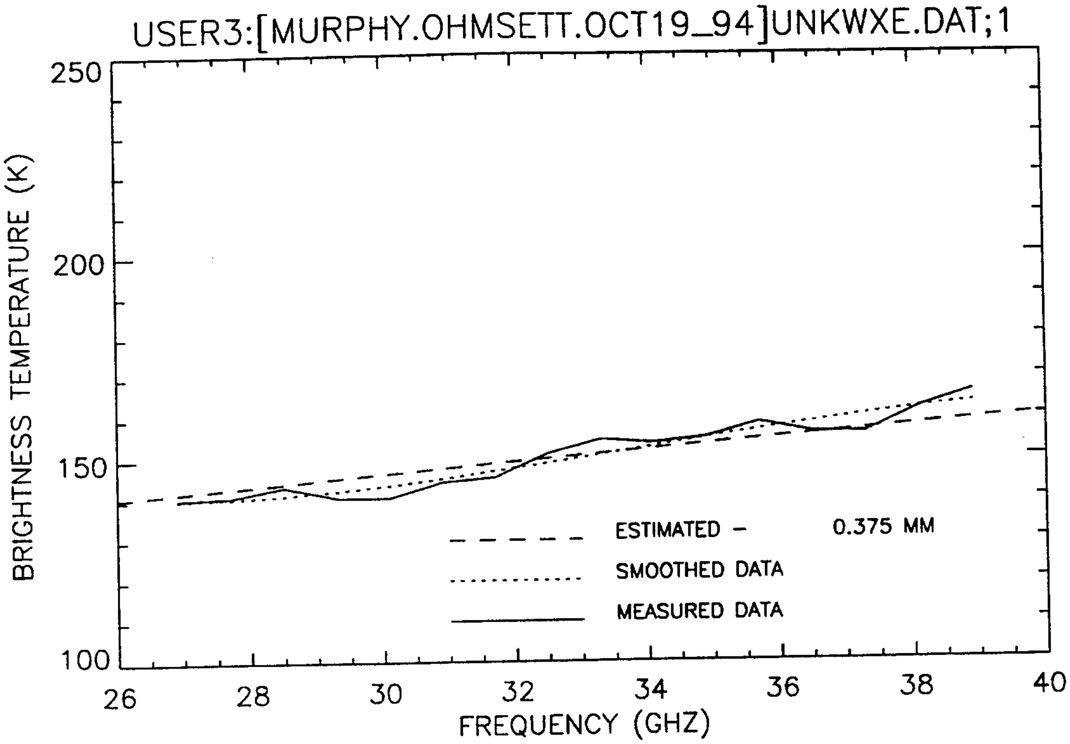

Figure G-51 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Wave Condition 1, 19 October 1994, Pass 5

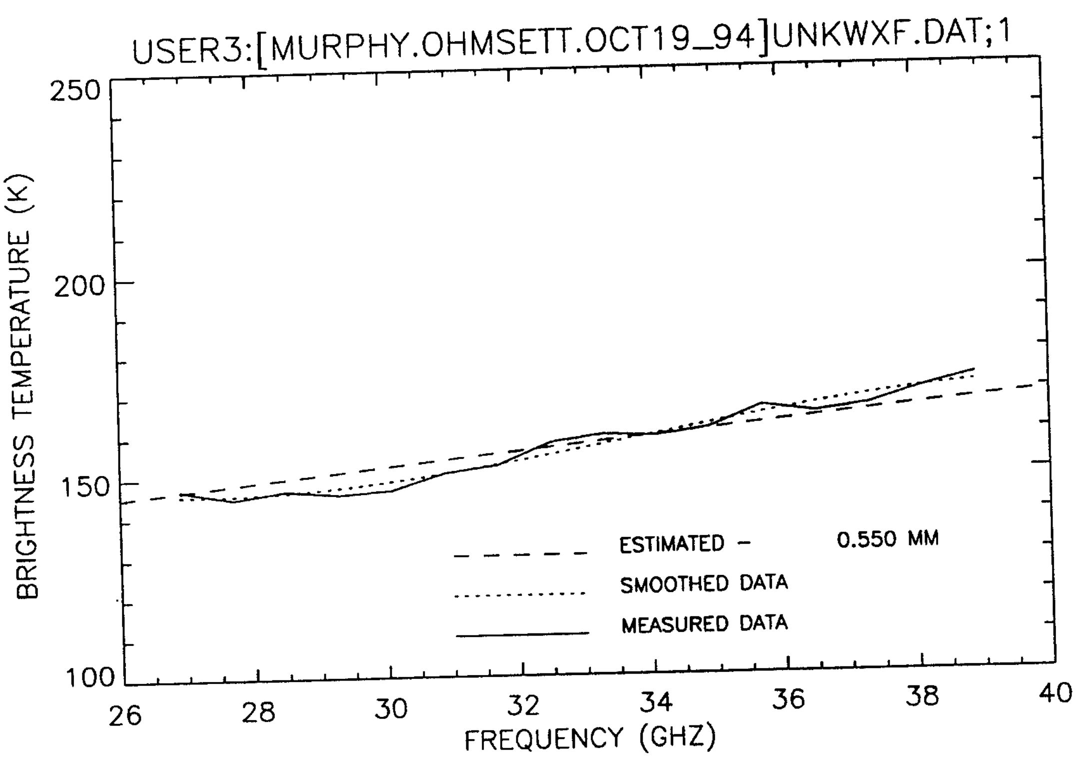

Figure G-52 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Wave Condition 1, 19 October 1994, Pass 6

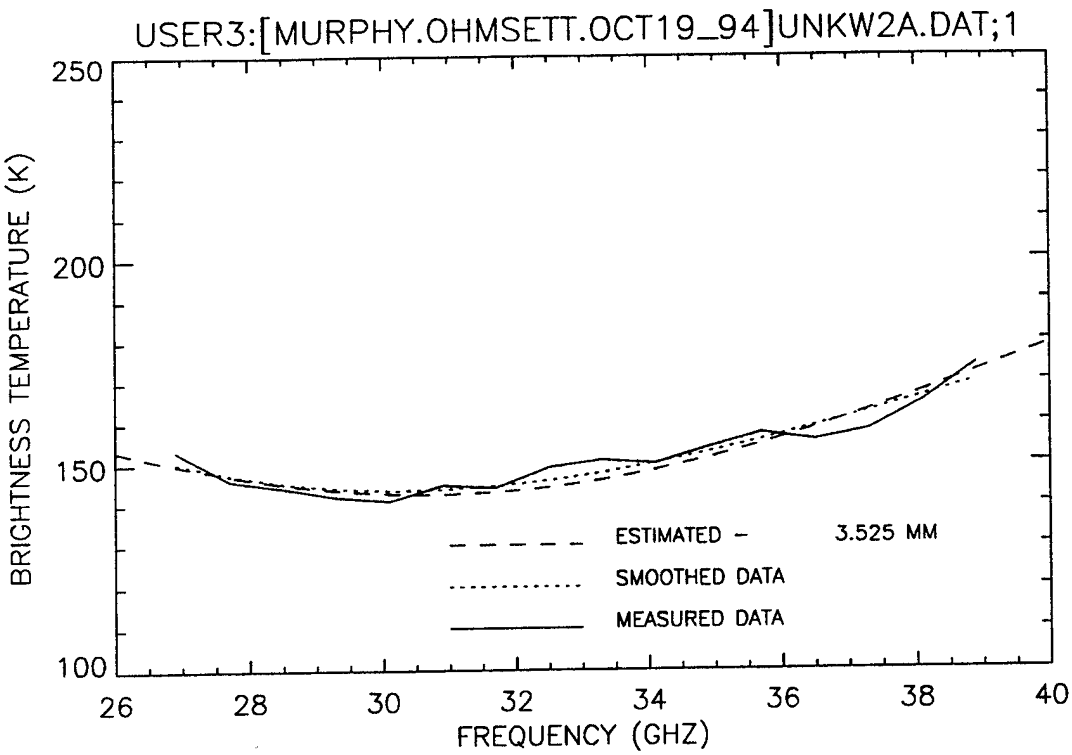

Figure G-53 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, Wave Condition 1, 19 October 1994, Pass 1

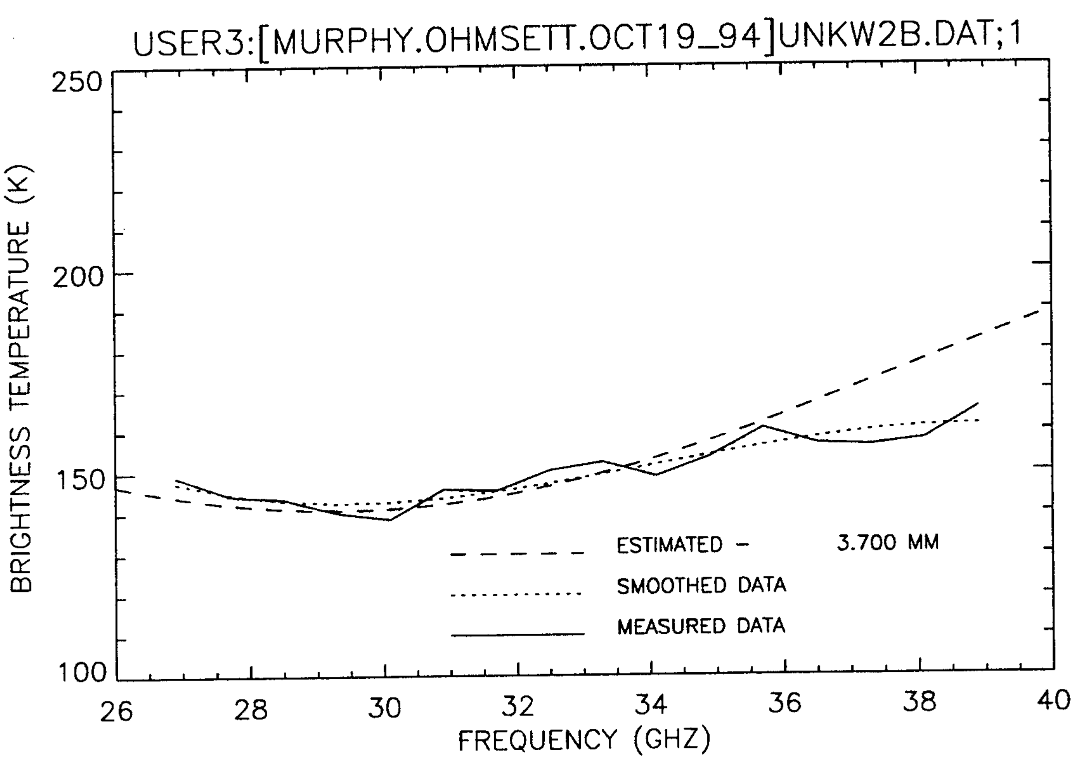

Figure G-54 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, Wave Condition 1, 19 October 1994, Pass 2

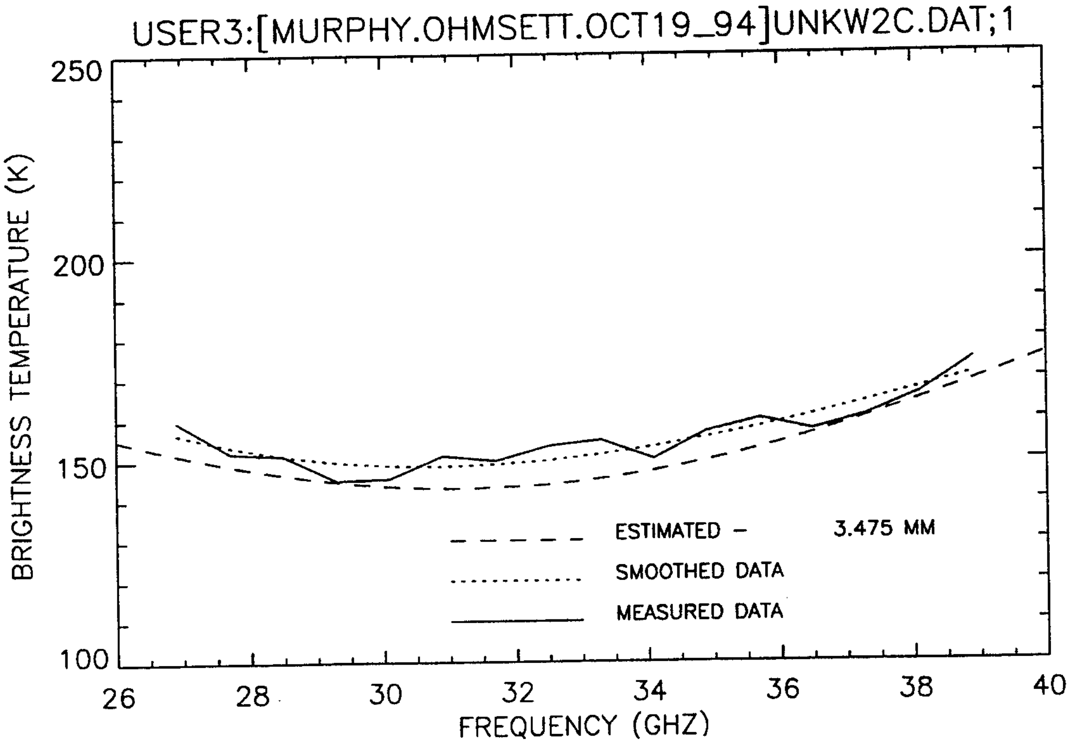

Figure G-55 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, Wave Condition 1, 19 October 1994, Pass 3

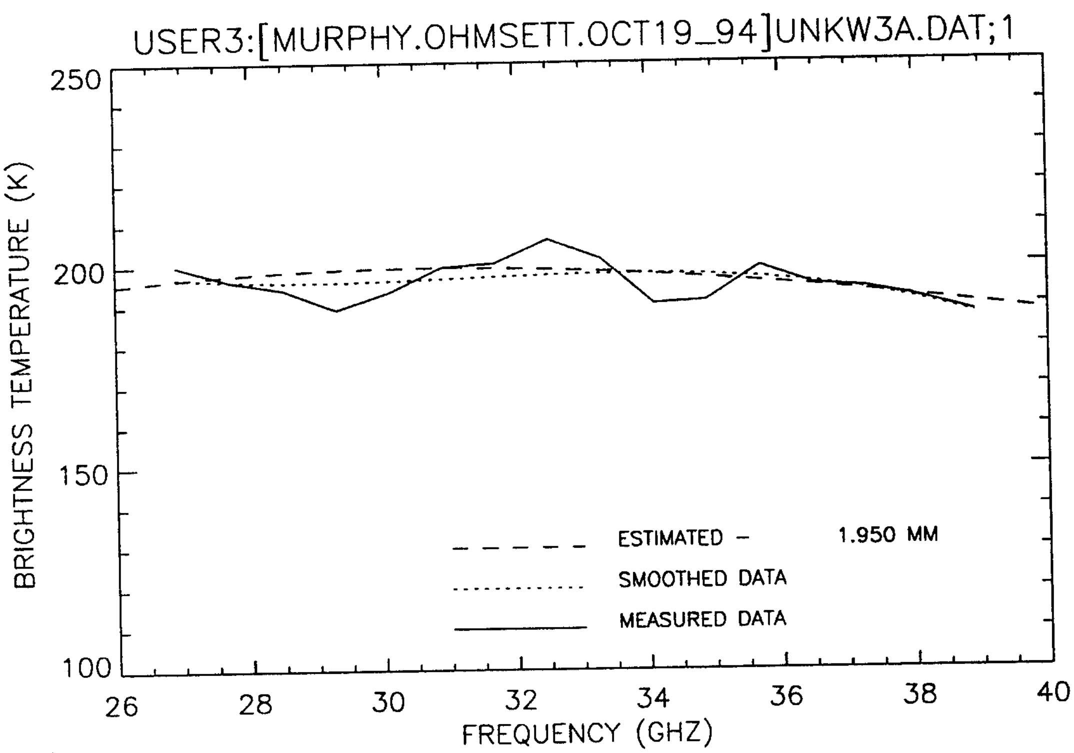

Figure G-56 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, Wave Condition 1, 19 October 1994, Pass 1

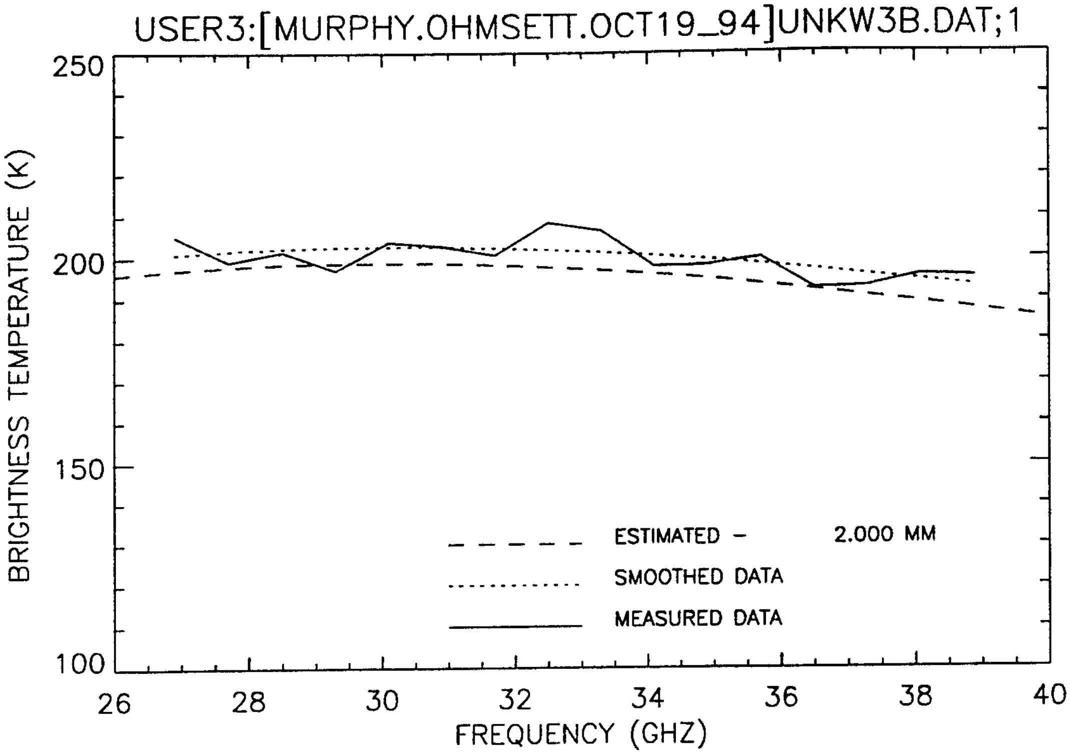

Figure G-57 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, Wave Condition 1, 19 October 1994, Pass 2

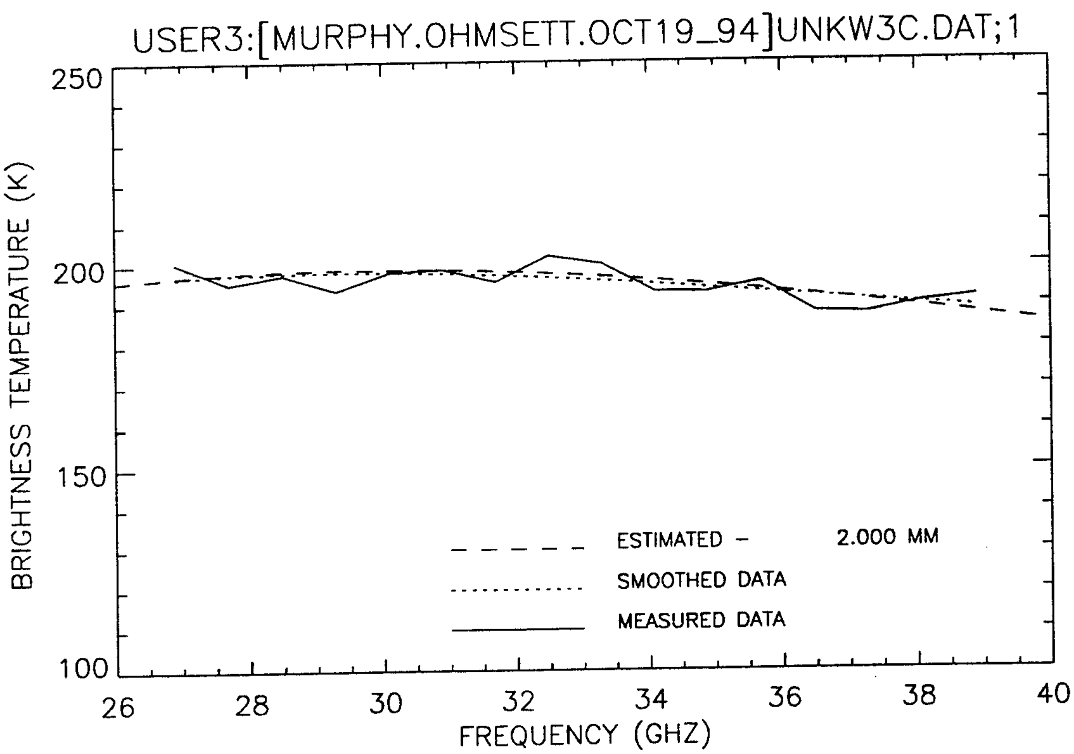

Figure G-58 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, Wave Condition 1, 19 October 1994, Pass 3

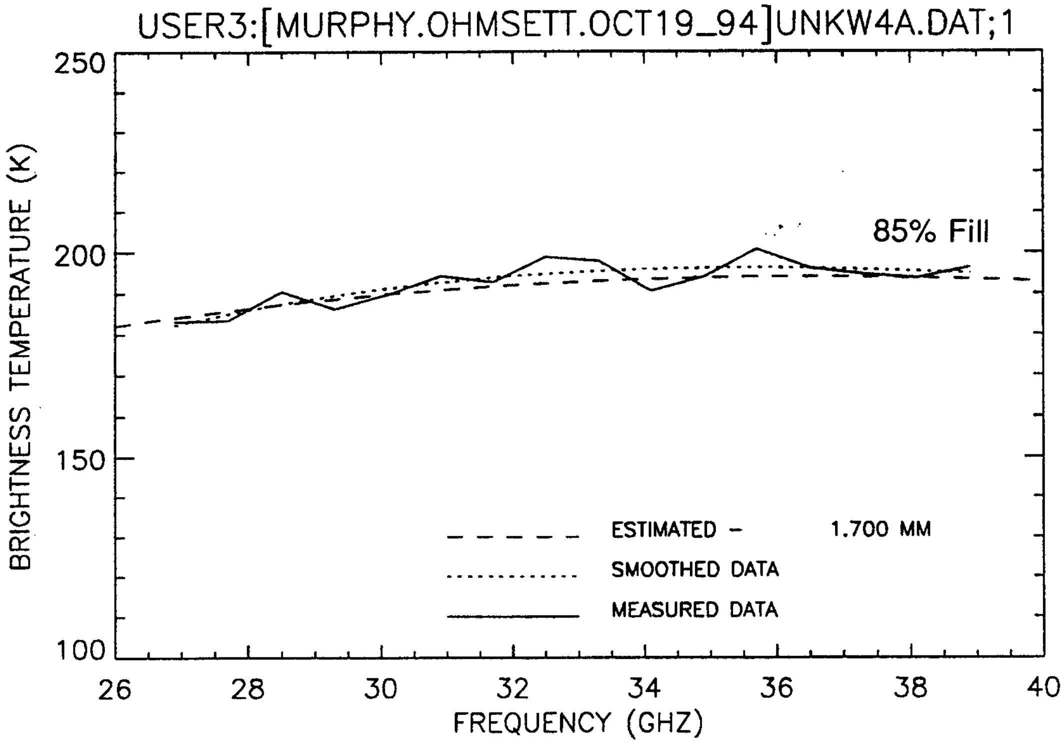

Figure G-59 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Wave Condition 1, 19 October 1994, Pass 1

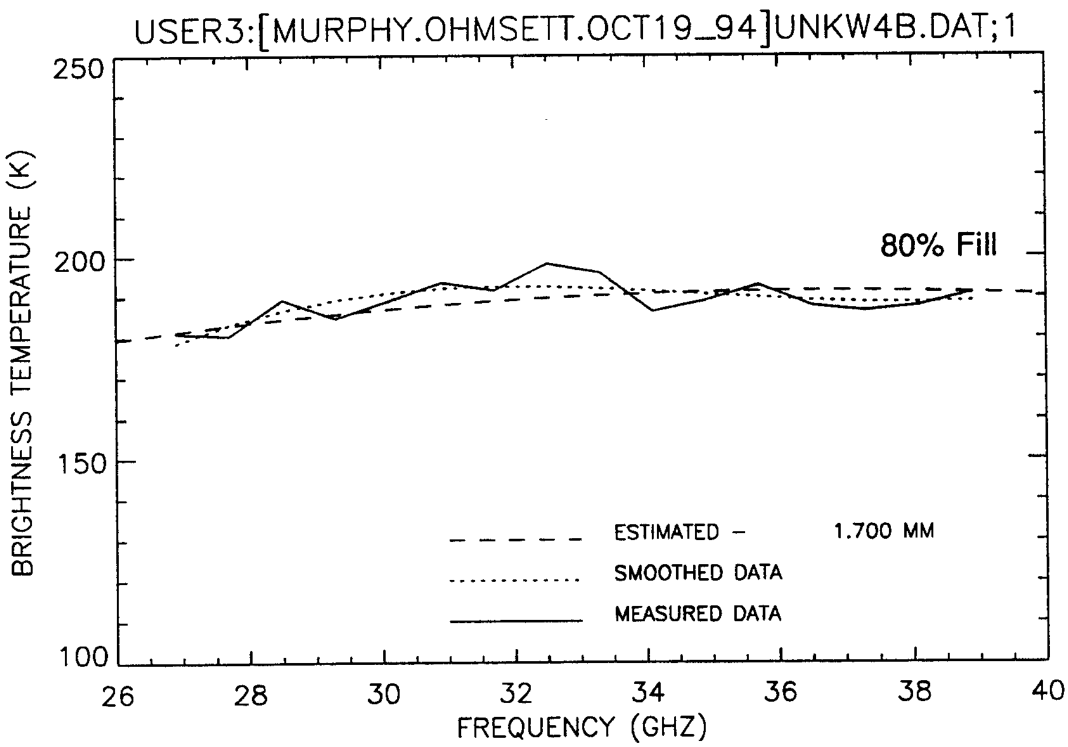

Figure G-60 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Wave Condition 1, 19 October 1994, Pass 2

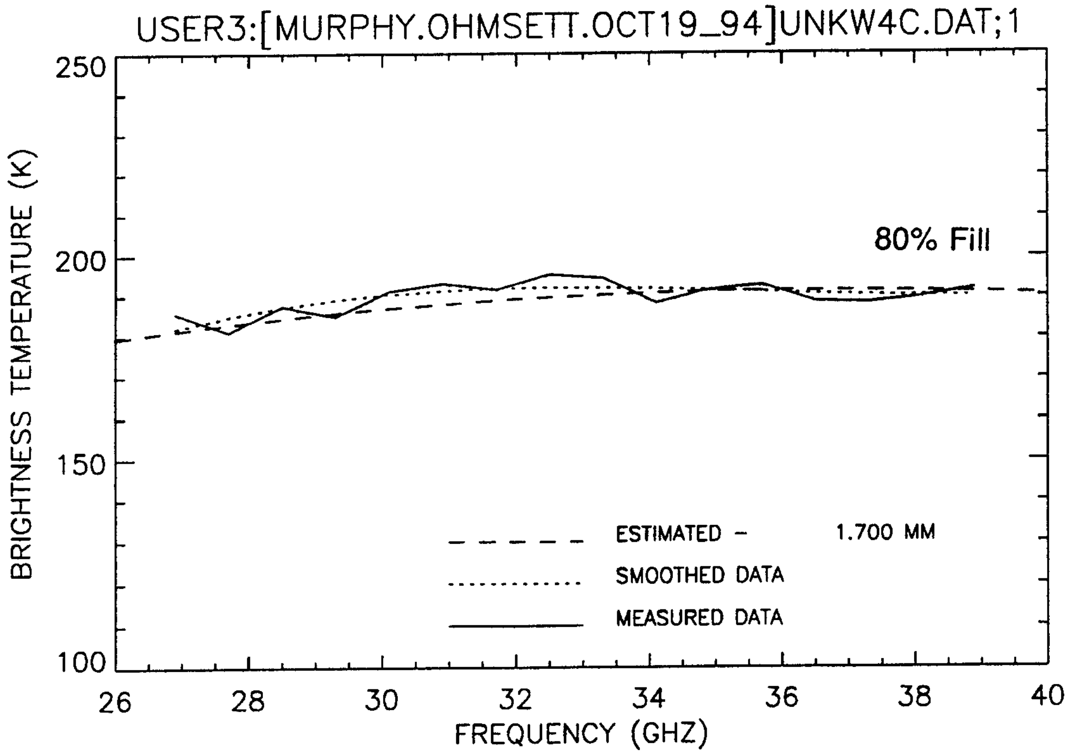

Figure G-61 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Wave Condition 1, 19 October 1994, Pass 3

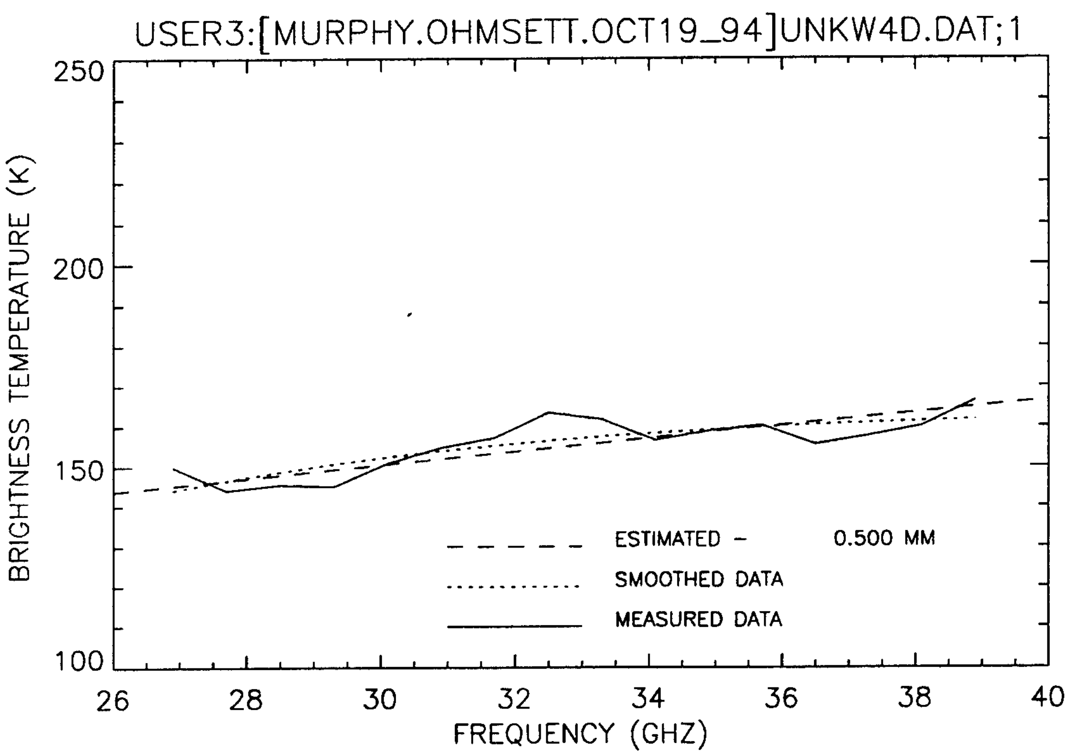

Figure G-62 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Wave Condition 1, 19 October 1994, Pass 4

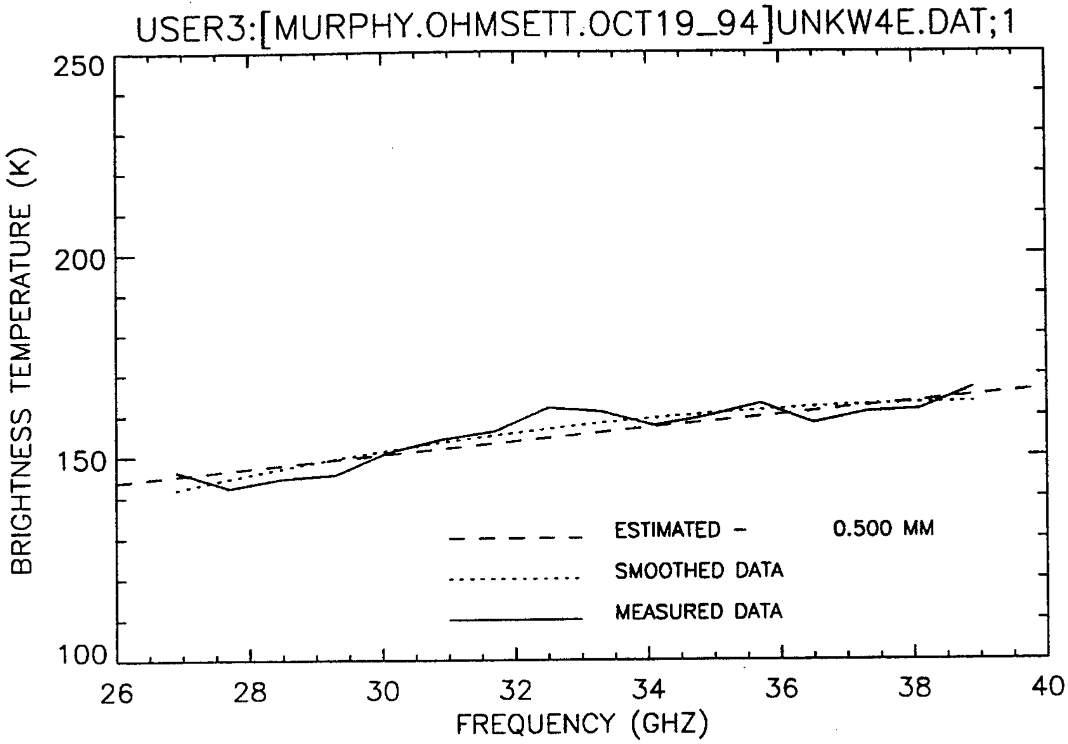

Figure G-63 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Wave Condition 1, 19 October 1994, Pass 5

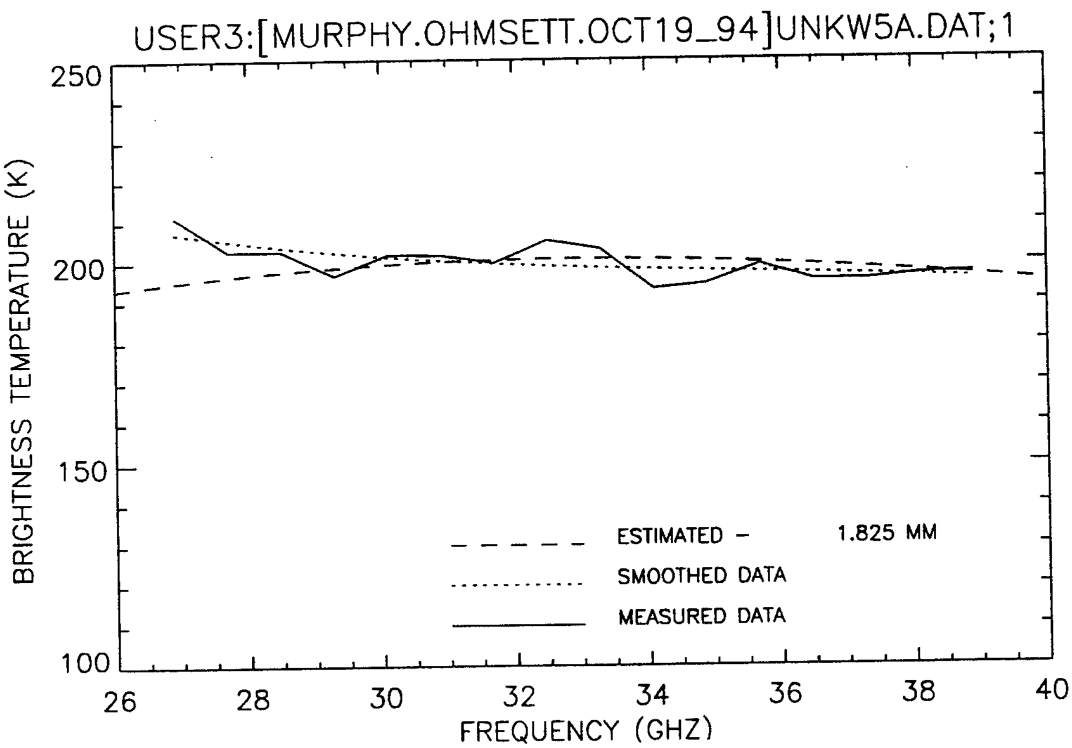

Figure G-64 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, Wave Condition 1, 19 October 1994, Pass 1

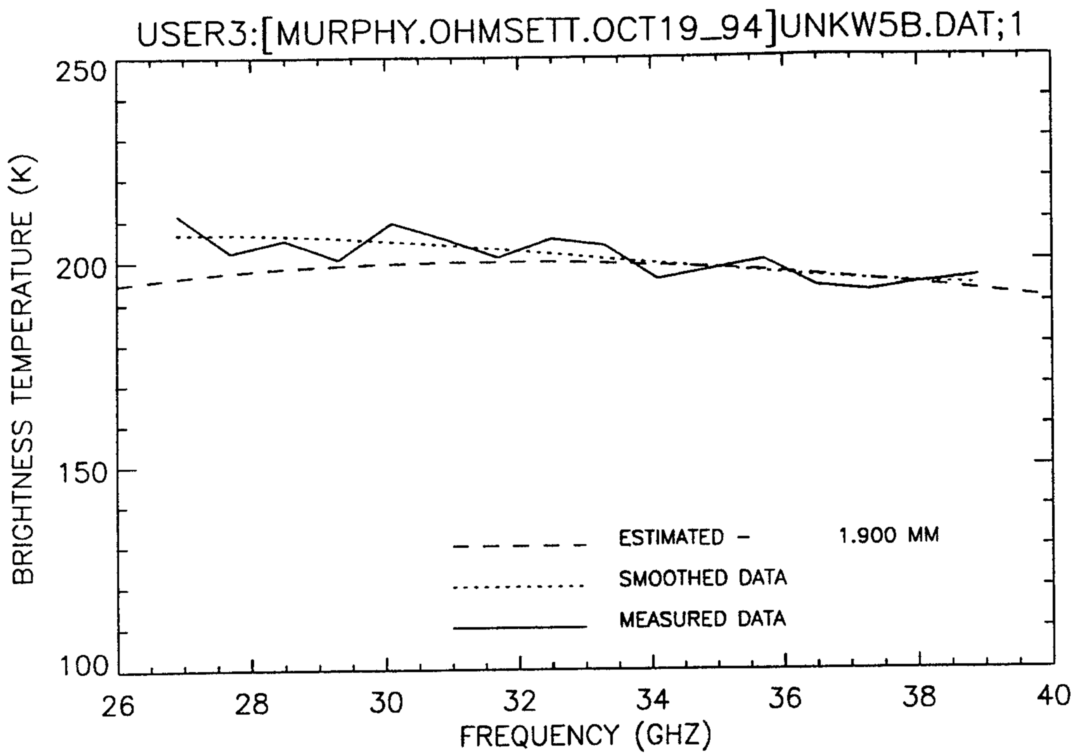

Figure G-65 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, Wave Condition 1, 19 October 1994, Pass 2

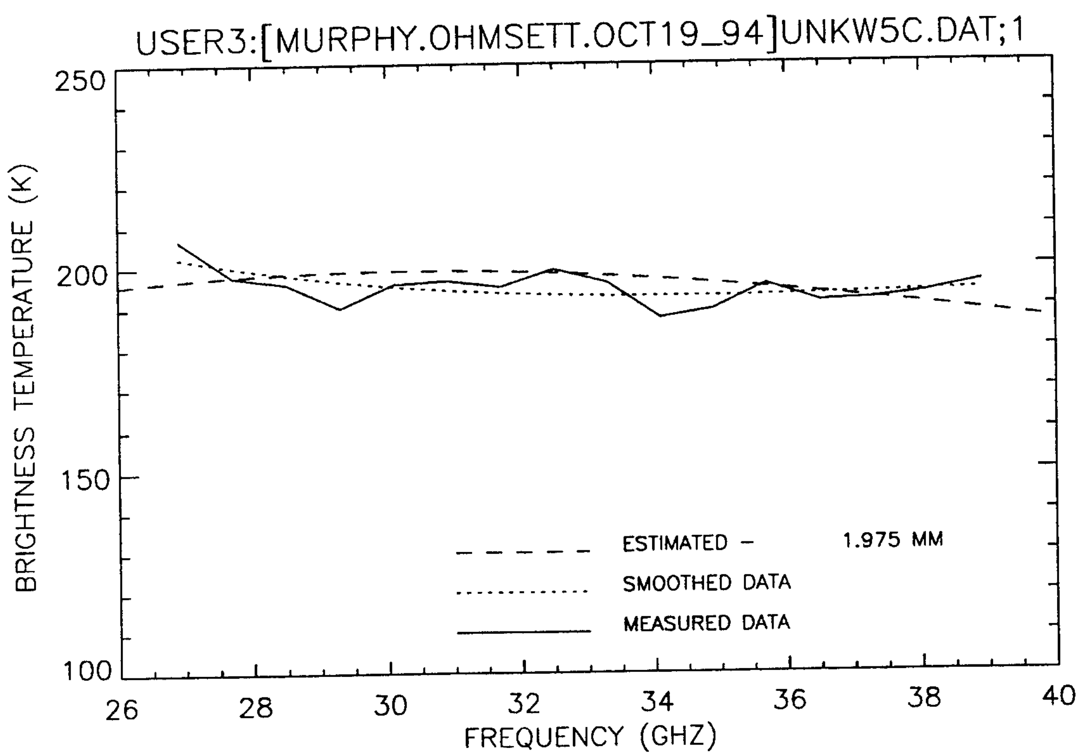

Figure G-66 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, Wave Condition 1, 19 October 1994, Pass 3

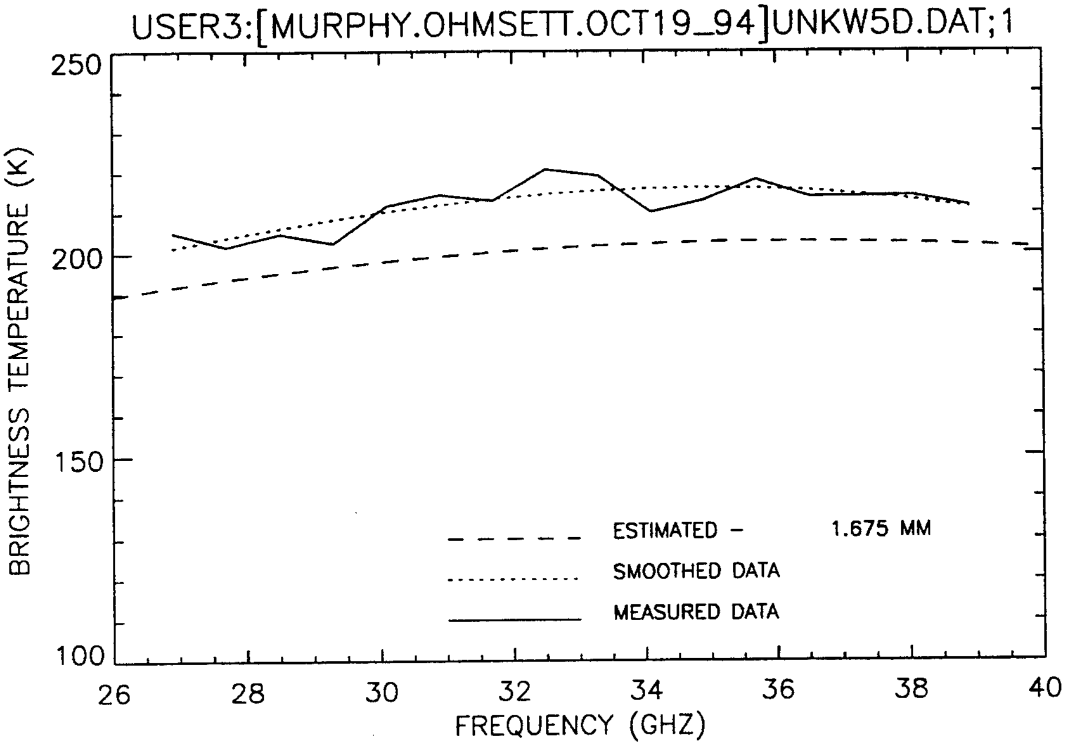

Figure G-67 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, Wave Condition 1, 19 October 1994, Pass 4

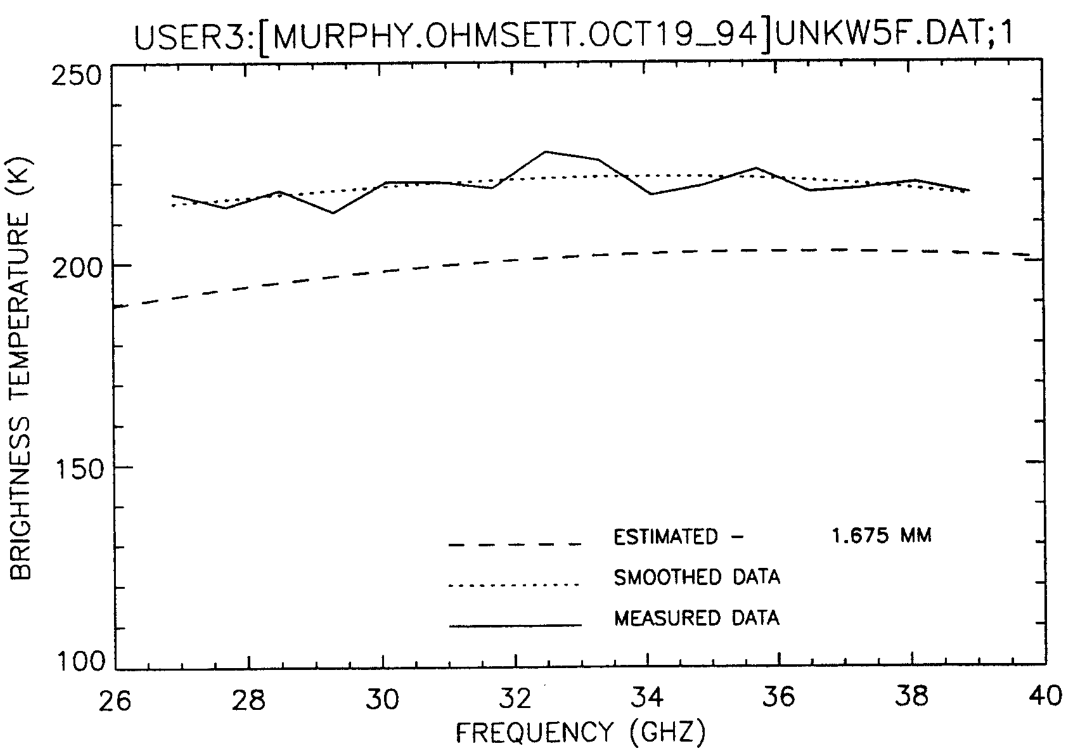

Figure G-68 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, Wave Condition 1, 19 October 1994, Pass 5

The wave generator was reset to create wave condition 2. Data collection commenced after the wave conditions had reached steady-state.

The water in the "clean" water target visually appeared to have some contamination on its surface. The following water measurements were collected between the water target (pool 6) and the most southern oil target (pool 5). The oil target pools were beginning to lose oil due to the waves. The following water measurements have a few very small tar balls in the antenna footprint; comparing the measured data to the laptop T^B water curve at the time of the measurement, the effect of these tar balls seemed insignificant.

UNKX6A - This curve was chosen to be the background water reference for this set of measurements.
UNKX6B - This curve is a fair match to the algorithm estimate of 0.000 mm.
UNKX6C - This curve is a good match to the algorithm estimate of 0.000 mm.

The main bridge was positioned over oil target pool 1, with the FSR aimed to the southwest corner of the oil target. The target is composed of 0.74 mm thick diesel oil covering 90% of the containment area. This area contained the largest oil quantity and measurement area for full antenna beam fill during the collection sweeps.

UNKX1A - This curve is a fair match to the algorithm estimate of 1.325 mm. The slope of the measured data curve is somewhat steeper than the theoretical estimate predicts.
UNKX1B - This curve is a poor-to-fair match to the algorithm estimate of 1.200 mm. The outlying measurement points at 30 GHz and 32.5 GHz seem to force the smoothed data plot to have more curvature (convex shape) than the estimate predicts.
UNKX1C - This curve is a fair match to the algorithm estimate of 1.100 mm. The convex shape of the smoothed curve seems to be due to the spikiness of the measurements below 32 GHz.

The main bridge was positioned over pool 2 to collect data from the center of the oil target pool. This target consisted of a 2.6 mm thickness of diesel oil covering 100% of the containment area.

UNKX2A - This curve is a fair match to the algorithm estimate of 0.625 mm.

UNKX2B - This curve is a fair match to the algorithm estimate of 3.900 mm. The noise in the measured data may be causing the smoothed curve to have a more distinct shape characteristic leading to the algorithm estimate of 3.9 mm.

UNKX2C - This curve is a fair-to-good match to the algorithm estimate of 0.775 mm.

UNKX2D - This curve is a good-to-excellent match to the algorithm estimate of 0.775 mm, although the measurement is a bit noisy.

The main bridge was positioned over pool 3 to collect data from the southern half oil target pool. This target consisted of a 2.0 mm thickness of a mixture of 75% diesel oil and 25% crude oil that completely filled the containment area. The oil in this half of the pool visually appeared thicker than in any other section of the target pool.

UNKX3A - This curve is a poor match to the algorithm estimate of 0.950 mm. The curve has a flat slope and is not a good match to any of the theoretical T^B versus frequency predictions. The result is inconclusive.

UNKX3B - This curve is a poor match to the algorithm estimate of 0.875 mm. The curve has a flat slope and is not a good match to any of the theoretical T^B versus frequency predictions. The result is inconclusive.

UNKX3C - This curve is a poor match to the algorithm estimate of 0.875 mm. The curve has a flat slope and is not a good match to any of the theoretical T^B versus frequency predictions. The result is inconclusive.

The main bridge was positioned over pool 4 to collect data from the "swirly" area in the target. This target consisted of a 1.7 mm thickness of a mixture containing 50% diesel oil and 50% waste oil covering 60% of the containment area.

UNKX4A - This curve is a poor match to the algorithm estimate of 1.650 mm. The overall high T^B indicates an emulsion or bubbles.

UNKX4B - This curve is a poor match to the algorithm estimate of 1.675 mm. The overall high T^B indicates an emulsion or bubbles.

UNKX4C - This curve is a poor match to the algorithm estimate of 1.675 mm. The overall high T^B indicates an emulsion or bubbles.

UNKX4D - This curve is a poor match to the algorithm estimate of 1.700 mm. The overall high T^B indicates an emulsion or bubbles.

The main bridge was positioned over pool 5 to collect data from the center of the oil target pool. This target consisted of a 2.5 mm thickness of a mixture containing 75% diesel oil and 25% waste oil that covered the entire containment area.

UNKX5A - This curve is a poor match to the algorithm estimate of 1.650 mm. The overall high T^B indicates an emulsion or bubbles; however, the curve does seem to have the shape characteristic of a 3.4 mm estimate (plotted).

UNKX5B - This curve is a poor match to the algorithm estimate of 1.700 mm. The overall high T^B indicates an emulsion or bubbles.

UNKX5C - This curve is a poor match to the algorithm estimate of 1.725 mm. The overall high T^B indicates an emulsion or bubbles.

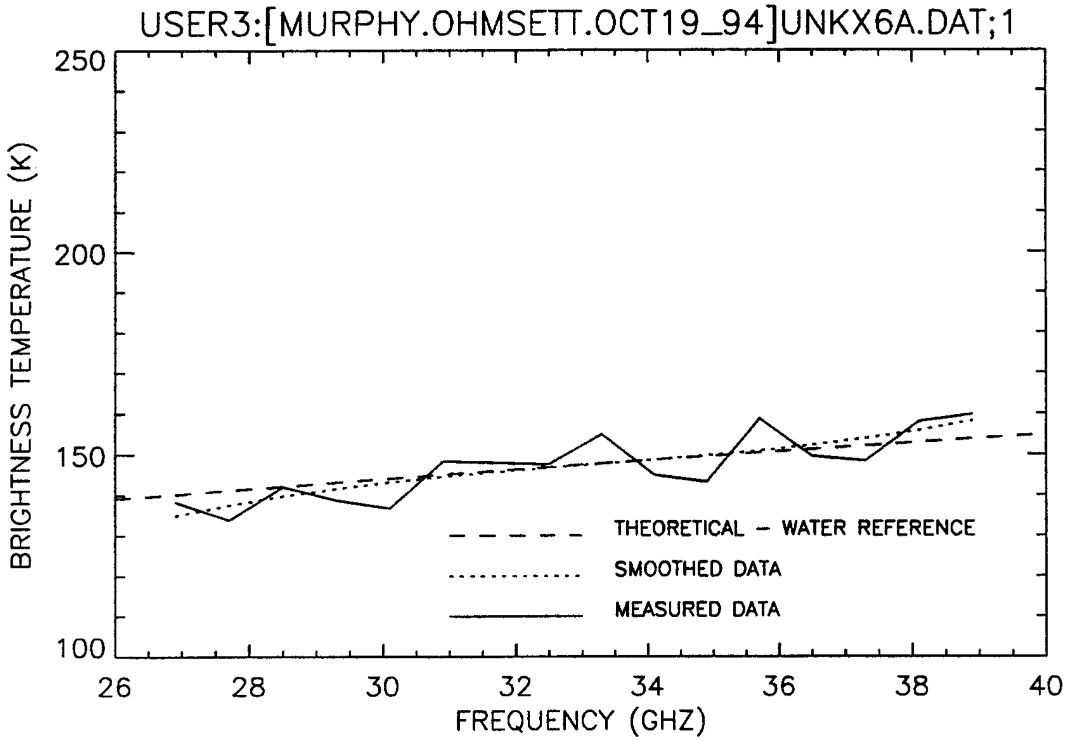

Figure G-69 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, Wave Condition 2, 19 October 1994, Pass 1

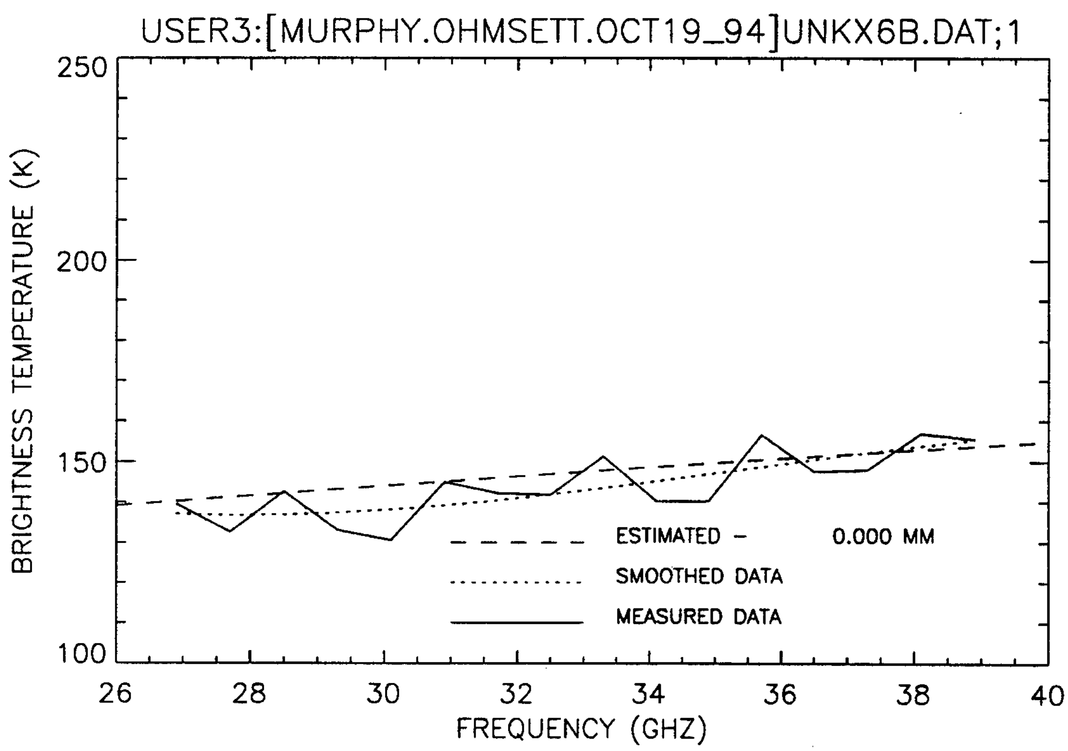

Figure G-70 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, Wave Condition 2, 19 October 1994, Pass 2

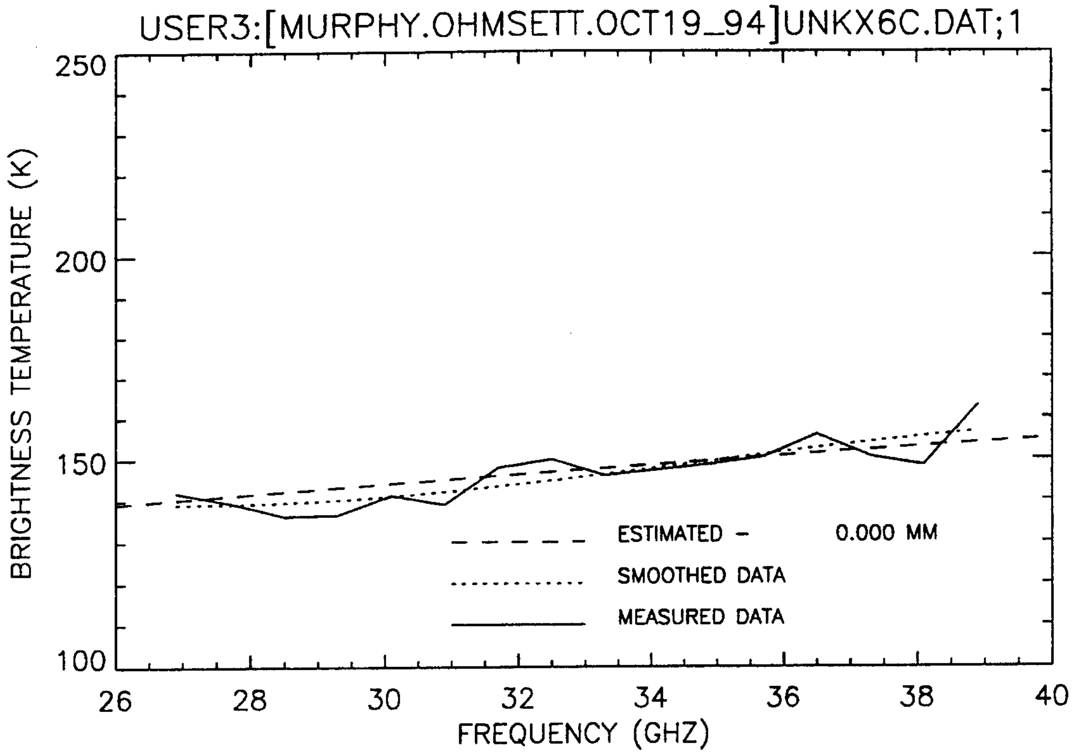

Figure G-71 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, Wave Condition 2, 19 October 1994, Pass 3

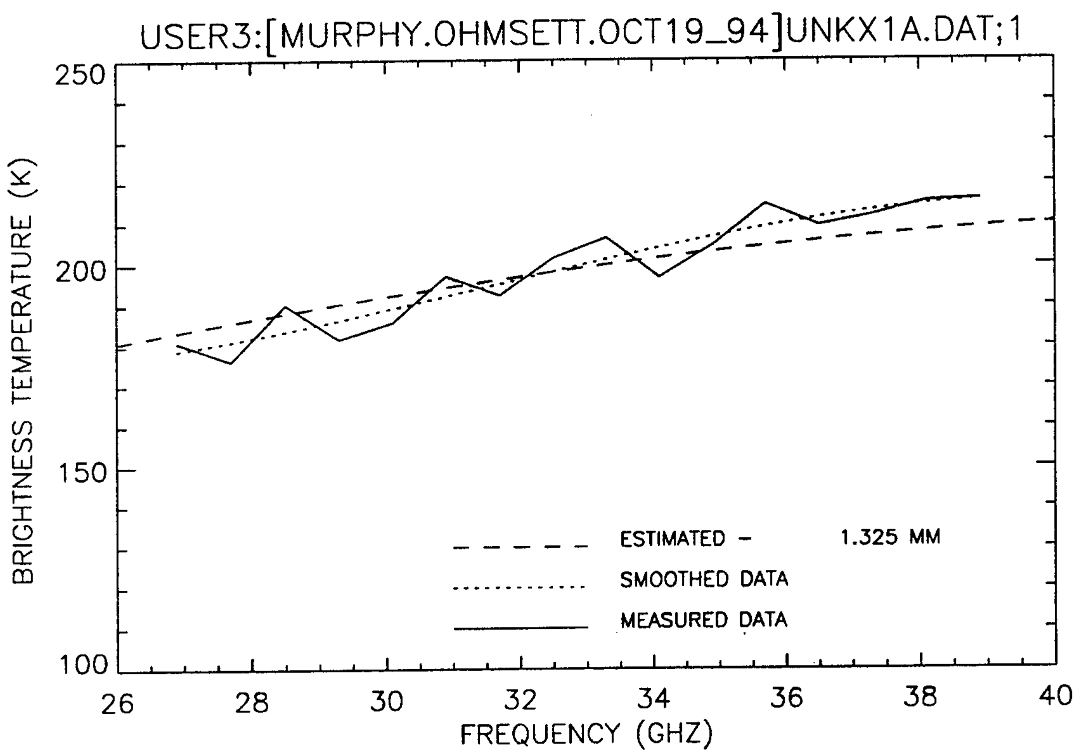

Figure G-72 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Wave Condition 2, 19 October 1994, Pass 1

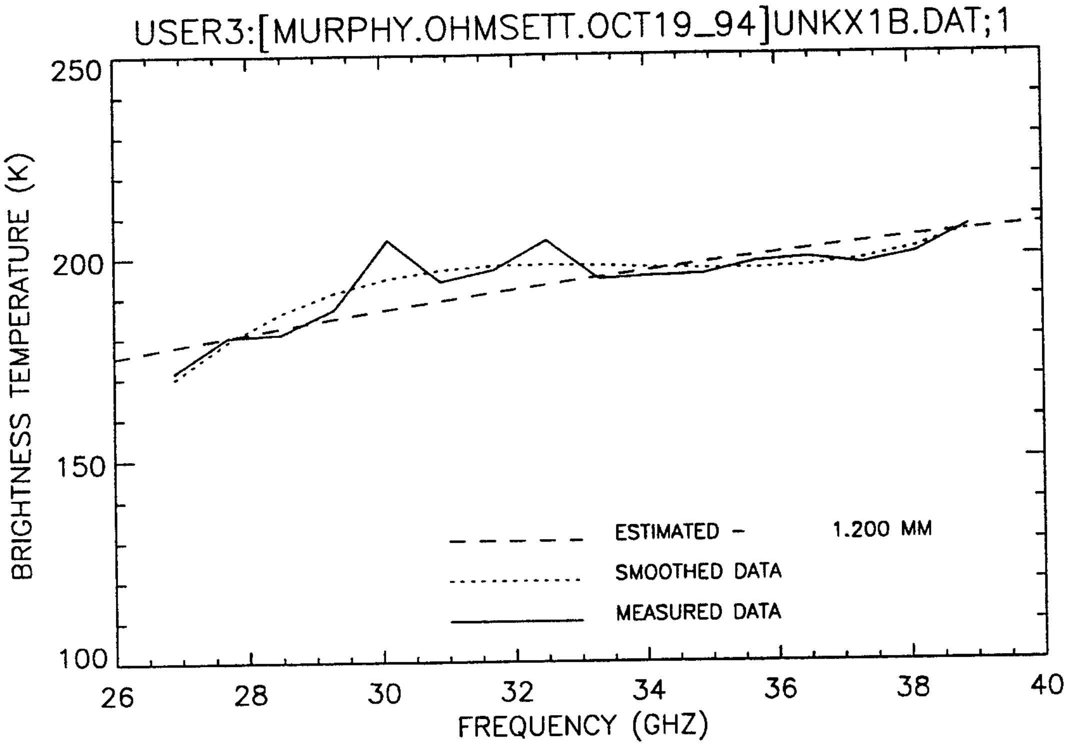

Figure G-73 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Wave Condition 2, 19 October 1994, Pass 2

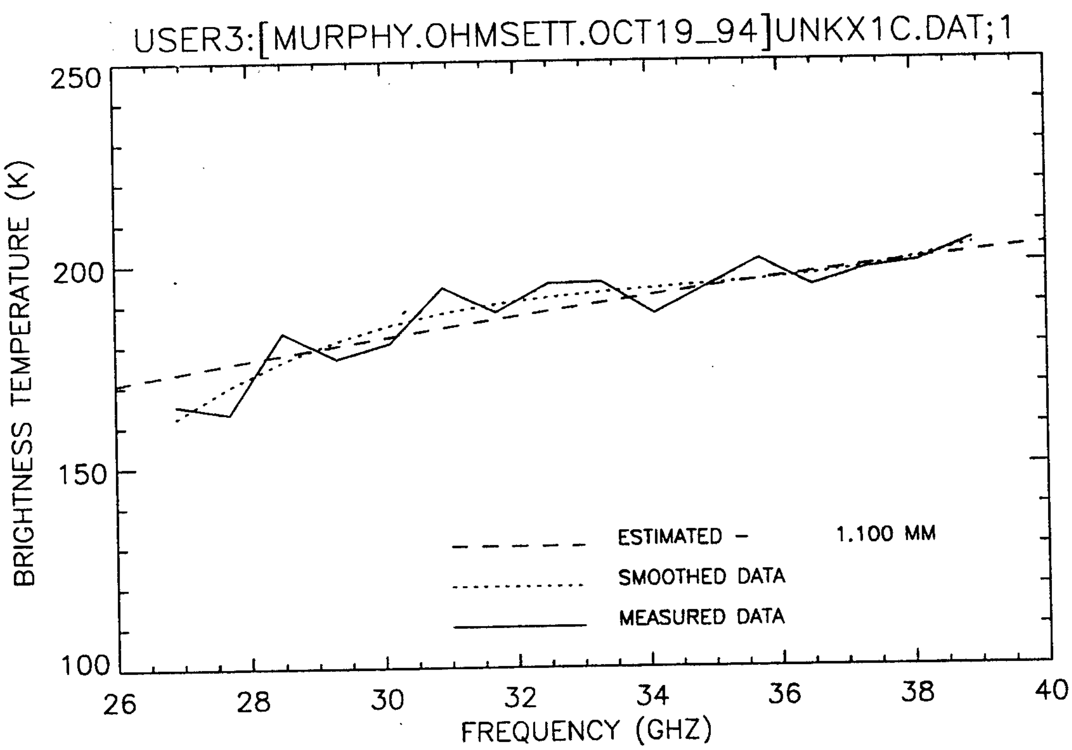

Figure G-74 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Wave Condition 2, 19 October 1994, Pass 3

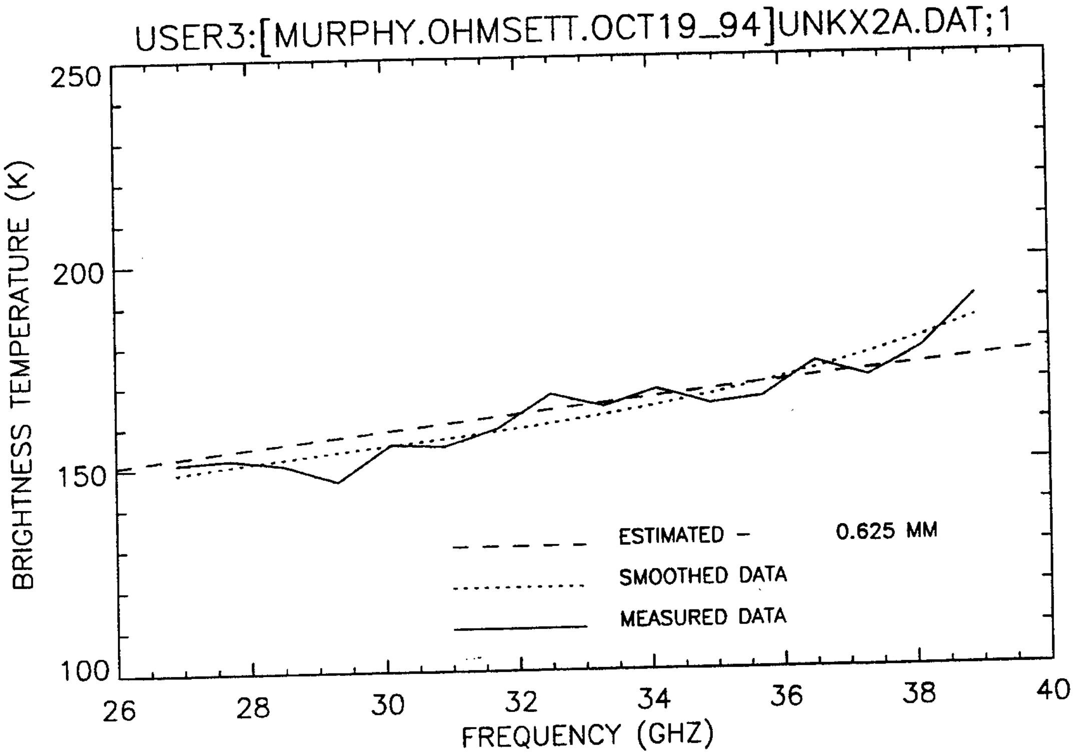

Figure G-75 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, Wave Condition 2, 19 October 1994, Pass 1

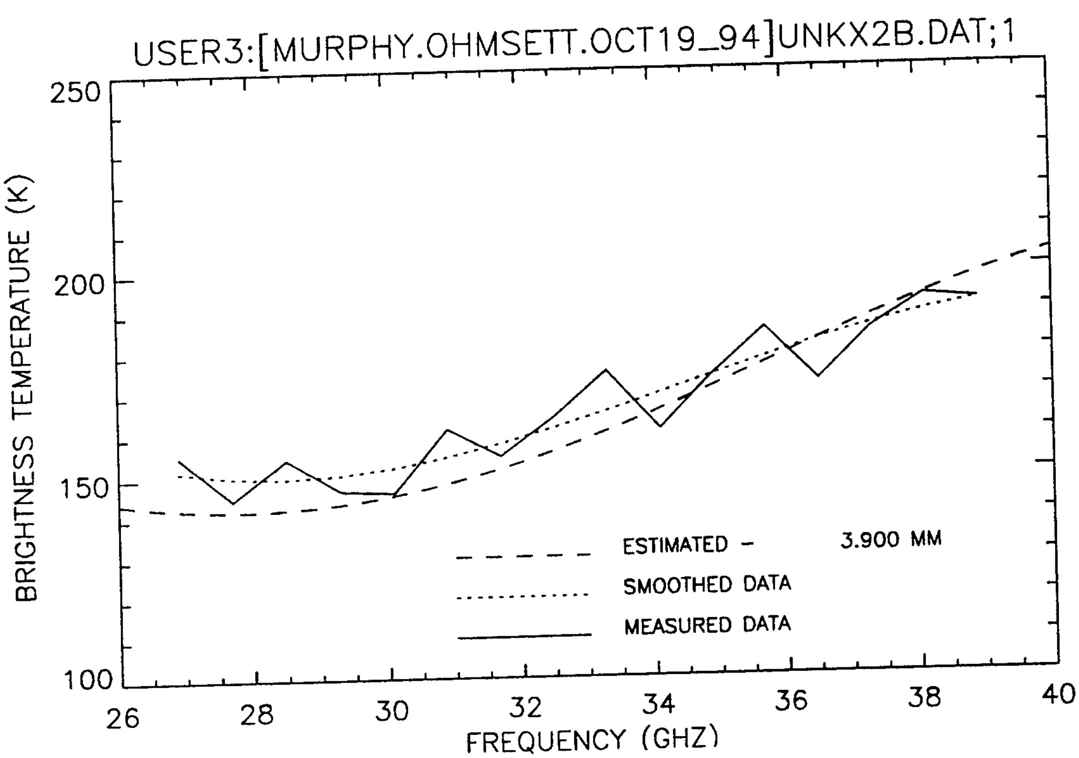

Figure G-76 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, Wave Condition 2, 19 October 1994, Pass 2

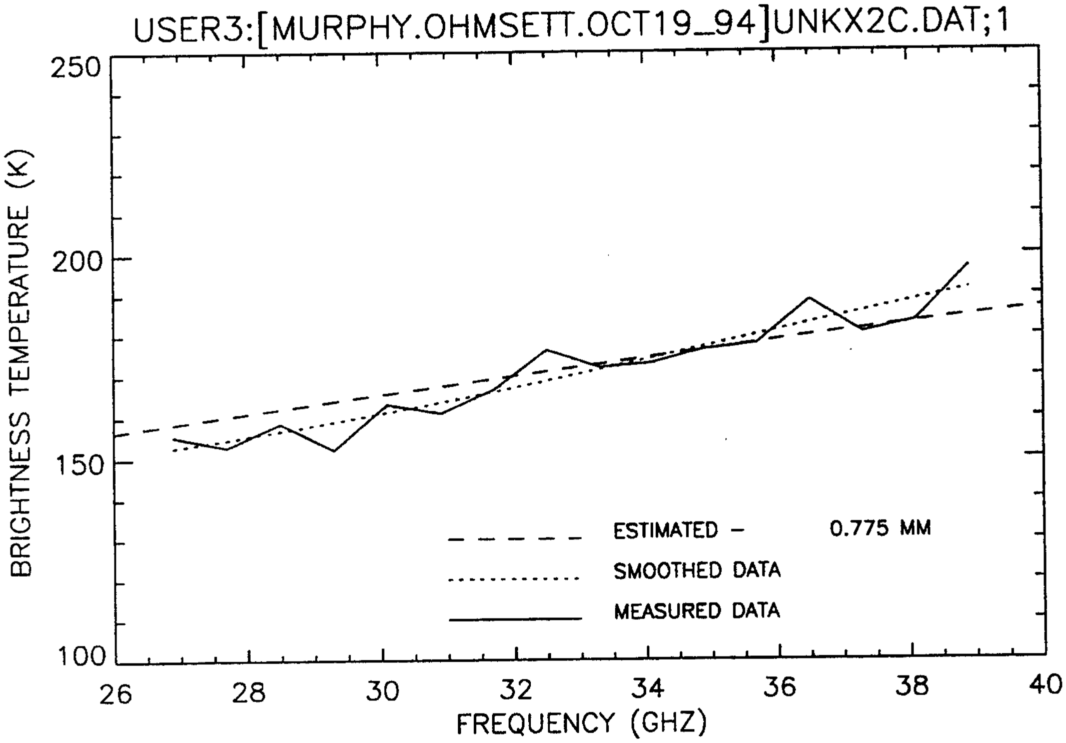

Figure G-77 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, Wave Condition 2, 19 October 1994, Pass 3

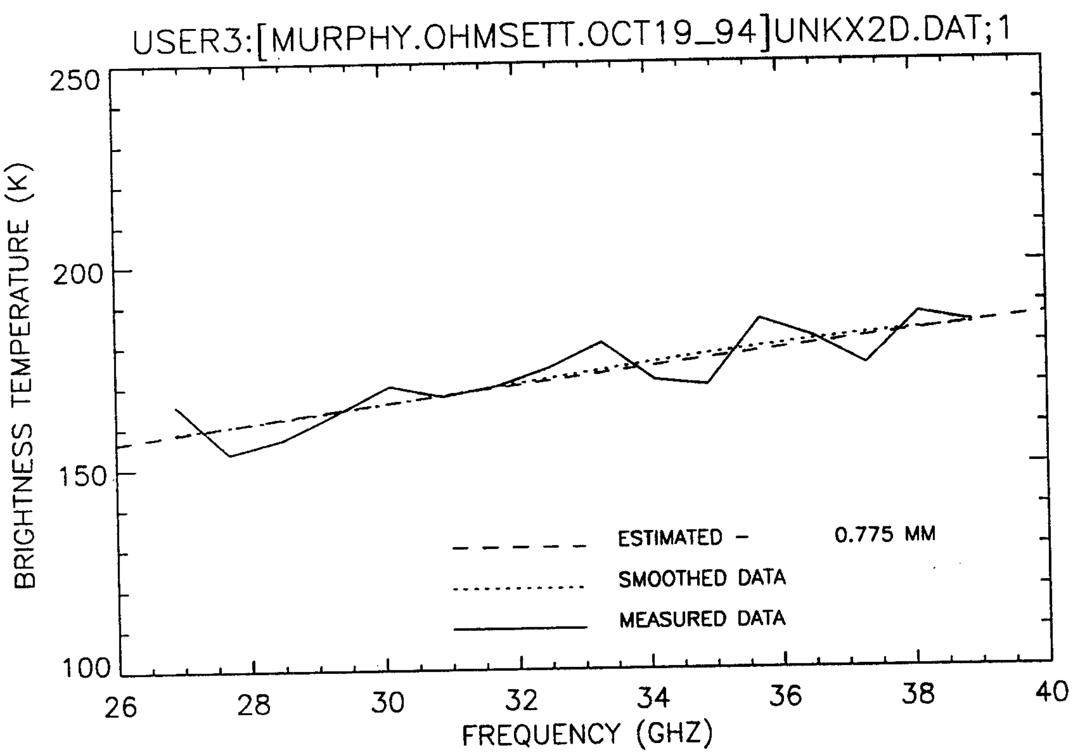

Figure G-78 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, Wave Condition 2, 19 October 1994, Pass 4

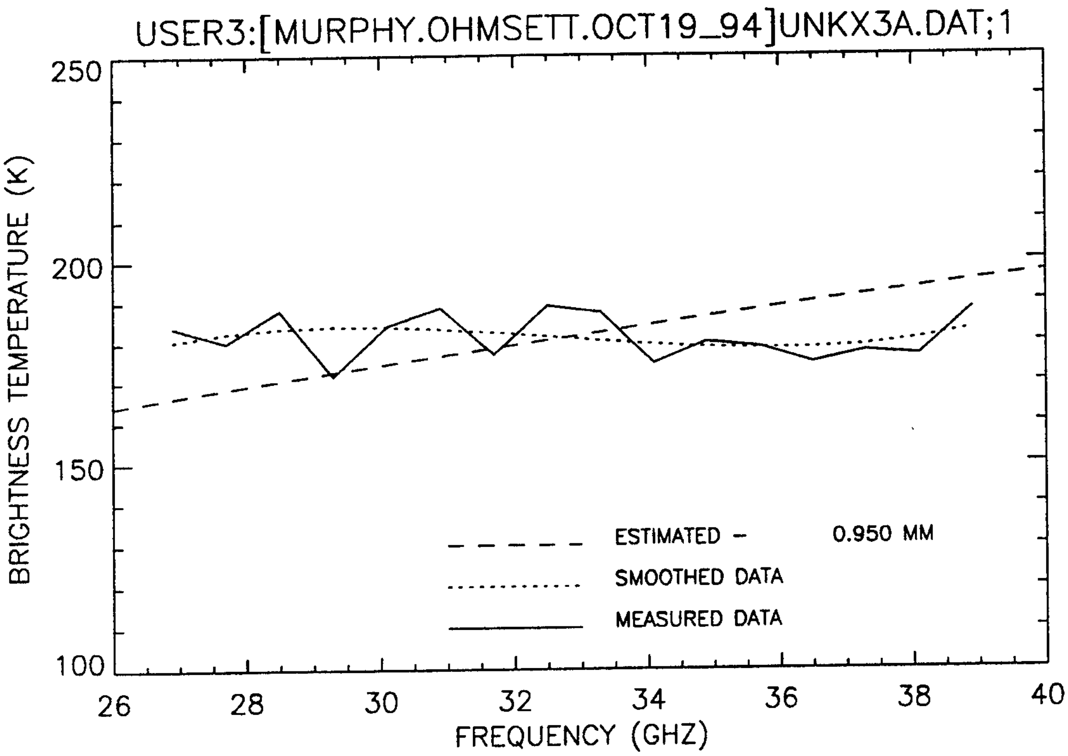

Figure G-79 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, Wave Condition 2, 19 October 1994, Pass 1

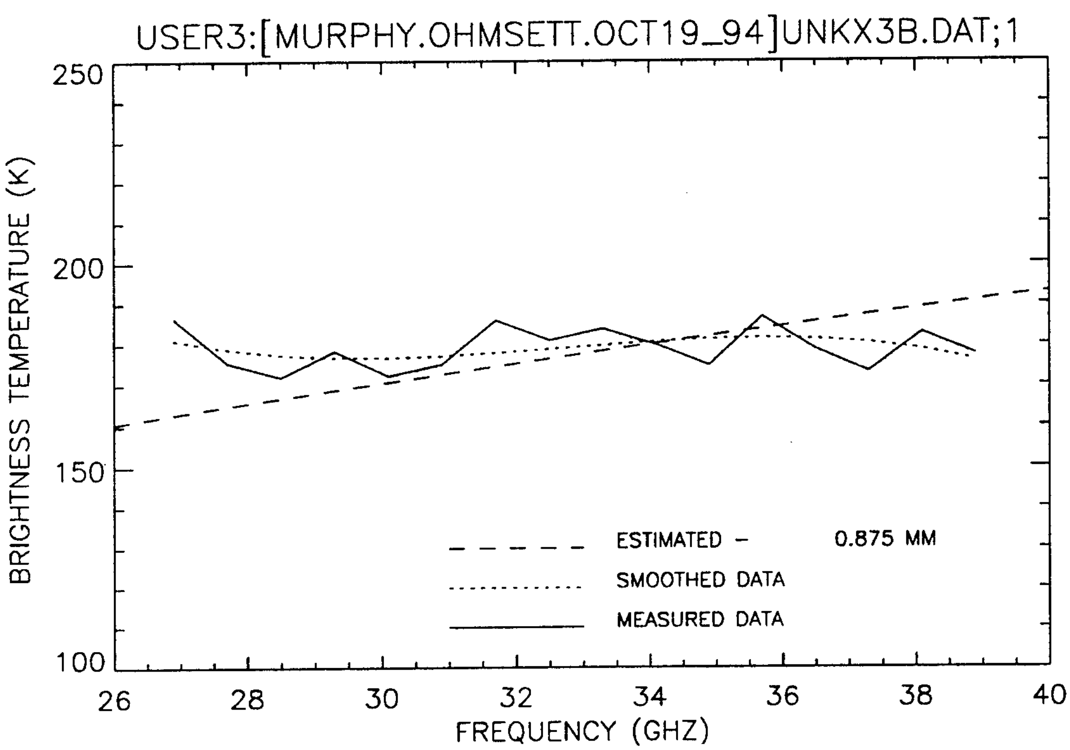

Figure G-80 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, Wave Condition 2, 19 October 1994, Pass 2

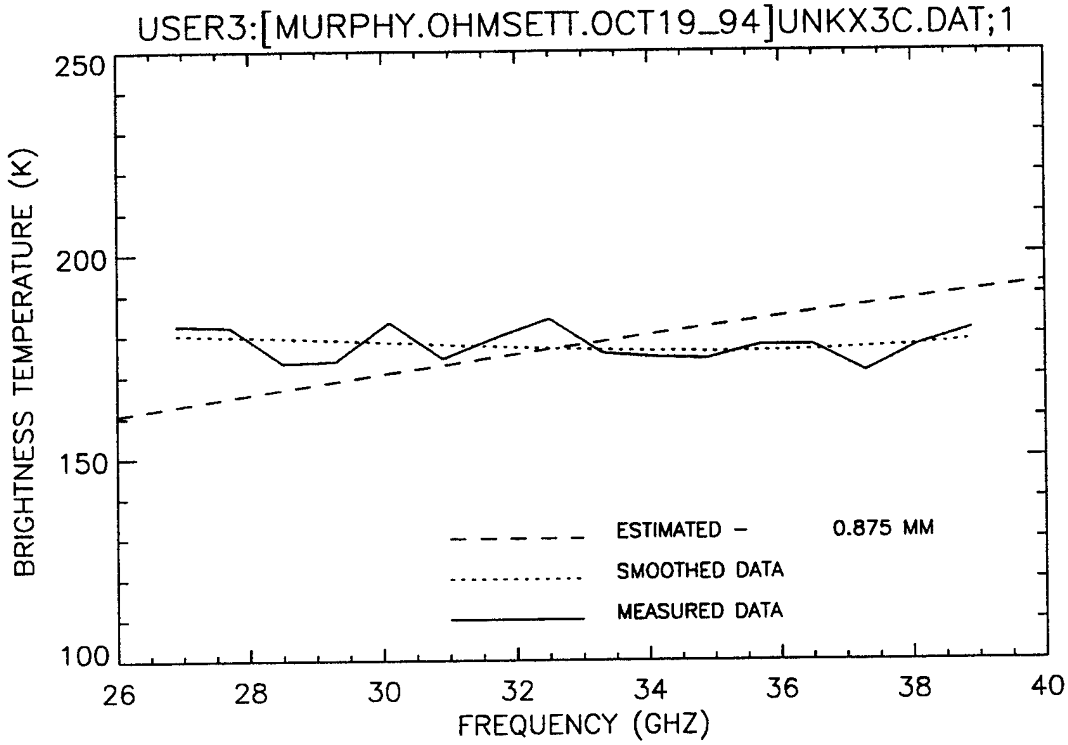

Figure G-81 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, Wave Condition 2, 19 October 1994, Pass 3

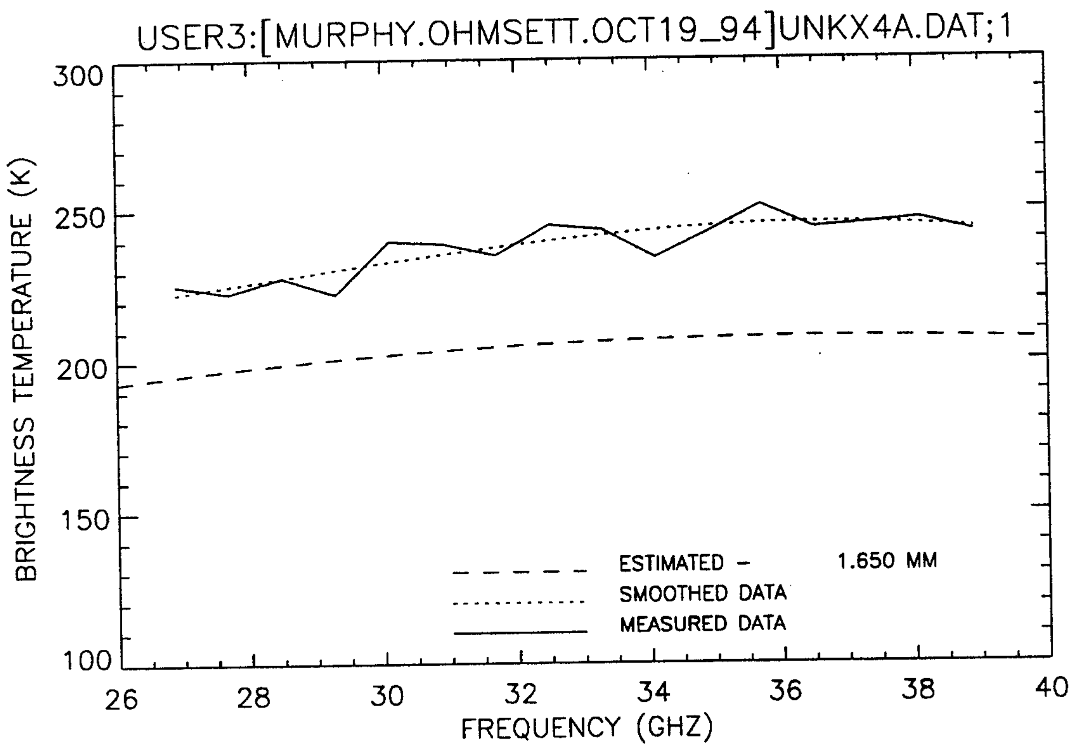

Figure G-82 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Wave Condition 2, 19 October 1994, Pass 1

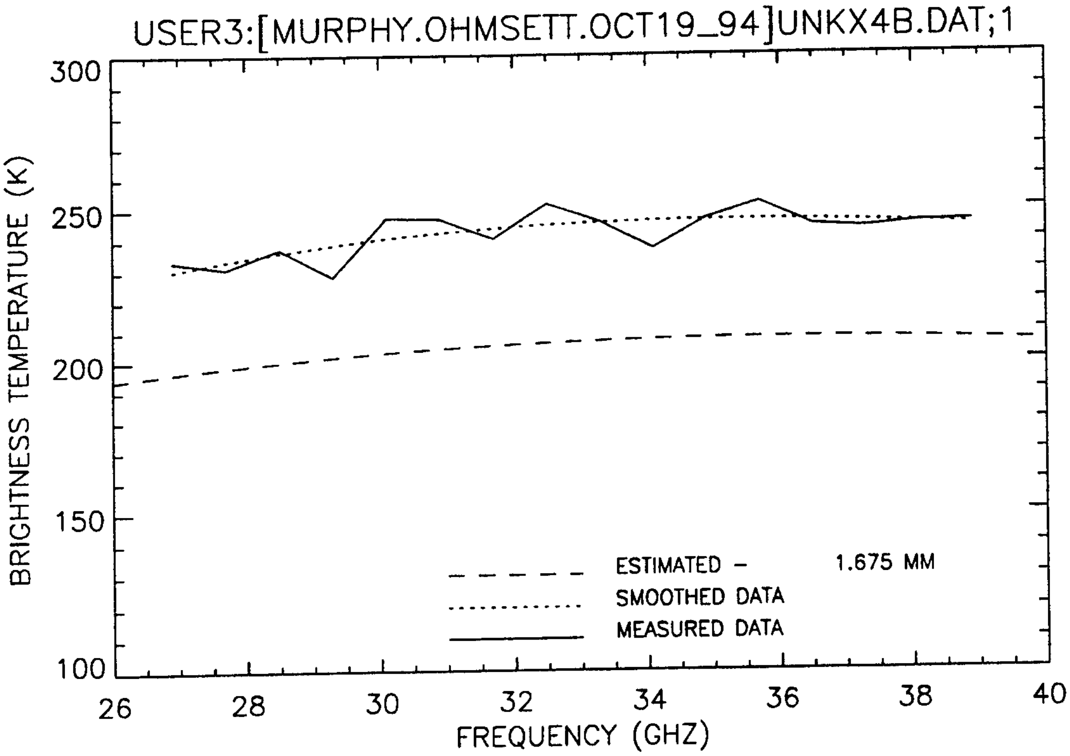

Figure G-83 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Wave Condition 2, 19 October 1994, Pass 2

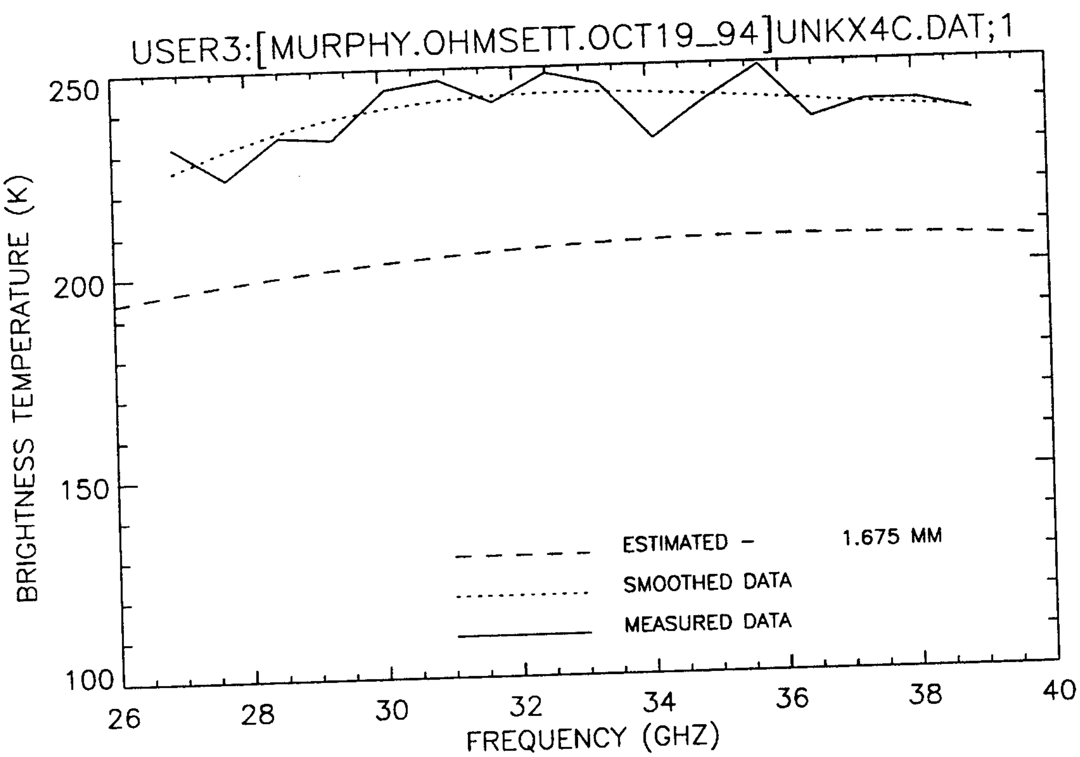

Figure G-84 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Wave Condition 2, 19 October 1994, Pass 3

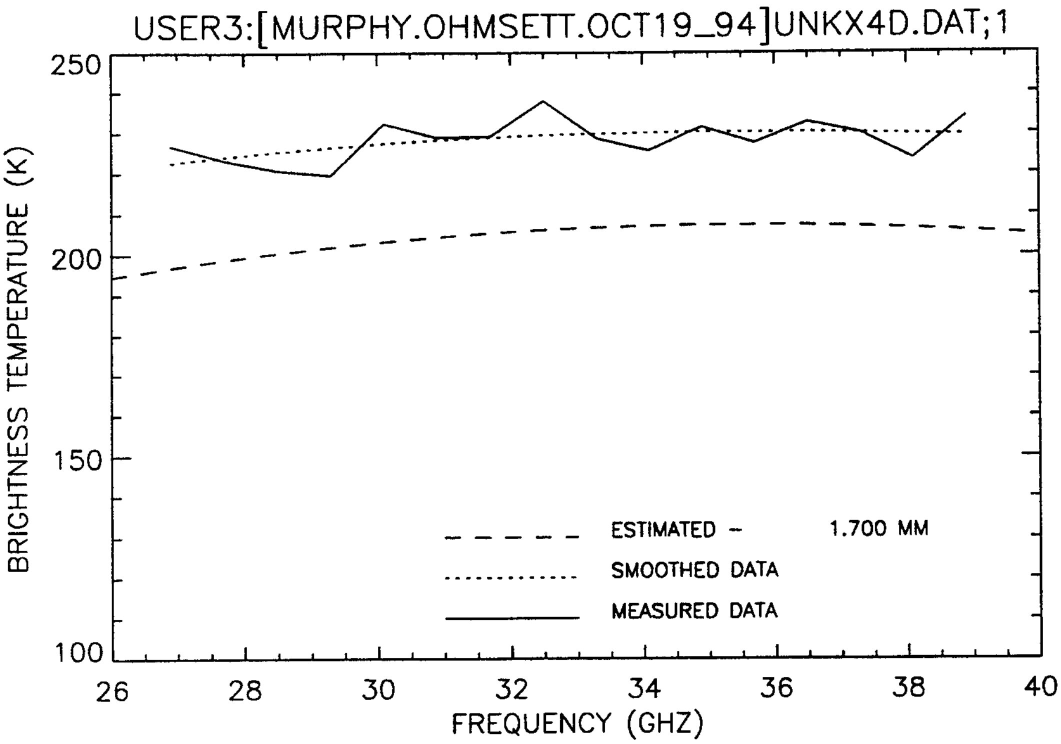

Figure G-85 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Wave Condition 2, 19 October 1994, Pass 4

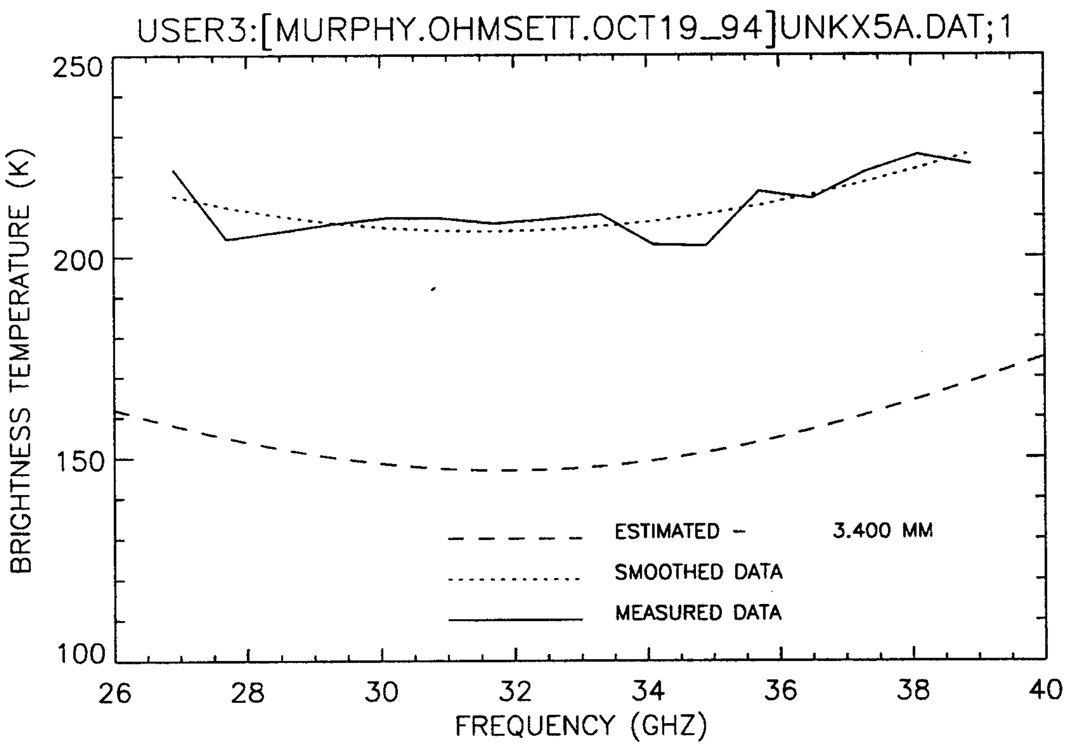

Figure G-86 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, Wave Condition 2, 19 October 1994, Pass 1

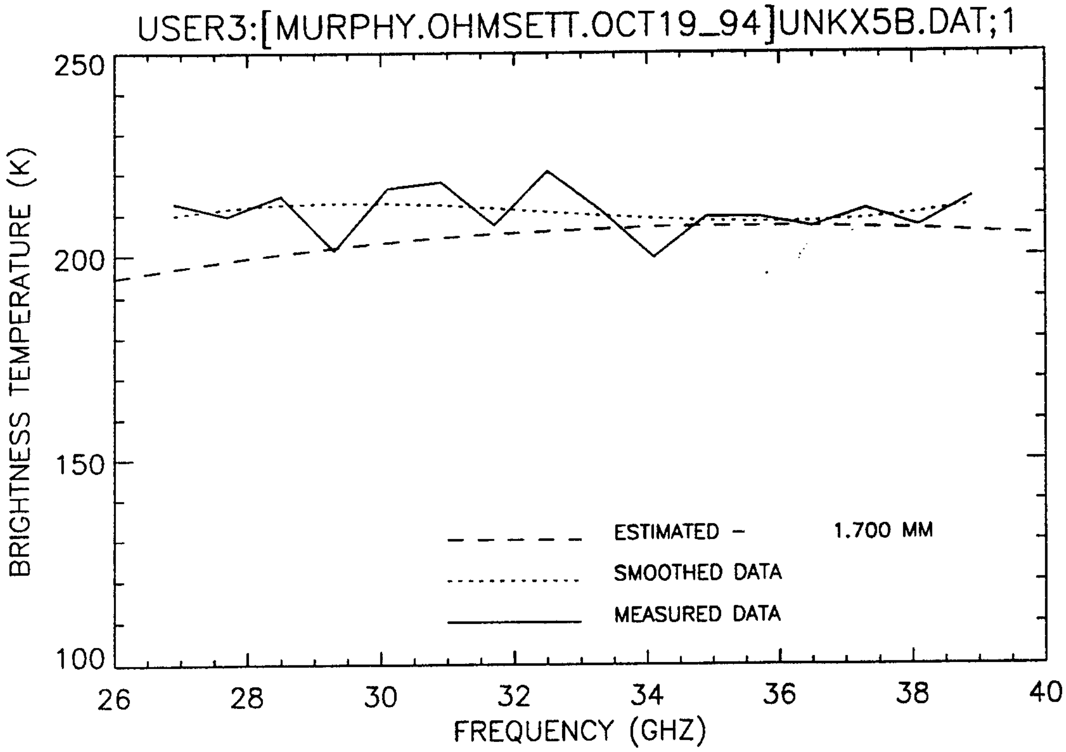

Figure G-87 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, Wave Condition 2, 19 October 1994, Pass 2

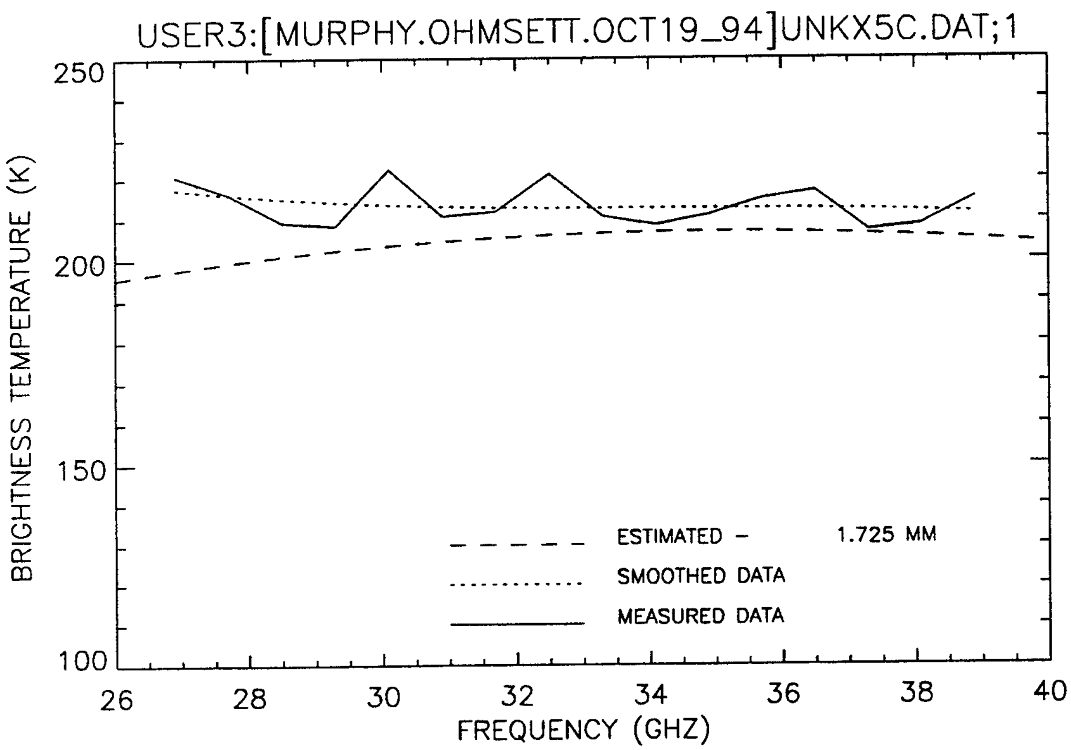

Figure G-88 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, Wave Condition 2, 19 October 1994, Pass 3

The wave generator was reset to provide chop condition 1. Measurements began after the chop condition had reached a steady state.

Since some oil had spilled outside of the containment areas, the slightly contaminated water-only pool was the "cleanest" area available for calibration. The following measurements were collected from pool 6.

UNKY6A - This curve was chosen as the background water reference for this data set.

UNKY6B - This curve is a fair match to the algorithm estimate of 0.000 mm, though the measured data curve seems to have a slightly steeper slope than the estimate would predict.

UNKY6C - This curve is a fair match to the algorithm estimate of 0.000 mm, though the measured data curve seems to have a slightly steeper slope than the estimate would predict.

The following measurements were collected from the center of oil target pool 1. This pool consisted of a 0.74 mm thickness of diesel oil covering 90% of the containment area. The surface of the oil is still clear of foam and bubbles.

UNKY1A - This curve is a fair-to-good match to the algorithm estimate of 0.775 mm, though the measured data curve seems to have a slightly steeper slope than the estimate would predict.

UNKY1B - This curve is a good match to the algorithm estimate of 0.925 mm, though the measured data curve seems to have a slightly steeper slope than the estimate would predict.

UNKY1C - This curve is a good match to the algorithm estimate of 1.000 mm.

UNKY1D - This curve is a good-to-excellent match to the algorithm estimate of 0.950 mm.

The following measurements were collected from the center of oil target pool 2. This target consisted of a 2.6 mm thickness of diesel oil that covered the entire containment area. The surface of the oil target does not contain any foam or bubbles.

UNKY2A - This curve is a poor match to the algorithm estimate of 0.675 mm. The 0.675 mm estimate is linear; however, this data set appears to have a curvature trait similar to the 3.5 mm estimate (plotted) though the overall measured T^B is slightly higher than the estimate predicts.

UNKY2B - This curve is a poor match to the algorithm estimate of 0.675 mm. The 0.675 mm estimate is linear; however, this data set appears to have a curvature trait similar to the 3.4 mm estimate (plotted), though the overall measured T^B is slightly higher than the estimate predicts.

UNKY2C - This curve is a poor-to-fair match to the algorithm estimate of 4.000 mm. The measured data seems to match the 4.0 mm estimate well at frequencies above 35 GHz, though it appears too linear below 34 GHz.

UNKY2D - This curve is a poor match to the algorithm estimate of 0.700 mm. The 0.700 mm estimate is linear; however, this data set appears to have a curvature trait similar to the 3.6 mm estimate (plotted), though the overall measured T^B is slightly higher than the estimate predicts.

The following measurements were collected from the center of oil target pool 3. This target consisted of a 2.0 mm thickness of a mixture of 75% diesel oil and 25% crude oil covering the entire containment area. The surface of this target does not contain any foam or bubbles.

UNKY3A - This curve is a poor match to the algorithm estimate of 1.775 mm. A 2.0 mm estimate (shown) is the closest visual match of the theoretical T^B predictions. The somewhat high overall T^B could indicate an emulsion; however, the shape of the curve does not match well with known emulsion shapes. The result is inconclusive.

UNKY3B - This curve is a poor match to the algorithm estimate of 1.725 mm. A better but only fair match is a 1.8 mm estimate.

UNKY3C - This curve is a fair match to the algorithm estimate of 1.750 mm.

The following measurements were collected from the center of oil target pool 4. This target consisted of a 1.7 mm thickness of a mixture of 50% diesel oil and 50% crude oil covering approximately 60% of the surface of the containment area. The oil target filled approximately 75% of the antenna footprint. The surface of the swirly target is beginning to change color to a more distinct lighter

brown color. The following measurements were made in an area that did not contain this swirly pattern.

UNKY4A - This curve is a good match to the algorithm estimate of 1.100 mm.

UNKY4B - This curve is an excellent match to the algorithm estimate of 1.125 mm.

UNKY4C - This curve is an excellent match to the algorithm estimate of 1.075 mm.

The main bridge was moved north to measure the "swirly" area of oil in pool 4. The following measurements have approximately 25 - 30% antenna beam fill.

UNKY4D - This curve is a poor-to-fair match to the algorithm estimate of 0.000 mm.

UNKY4E - This curve is a poor-to-fair match to the algorithm estimate of 0.225 mm. The slope of the measured data does not match the estimated curve well.

The following measurements were taken from the south part of the oil target pool 5. This target consisted of a 2.5 mm thickness of a mixture of 75% diesel oil and 25% waste oil that covered the entire containment area. The pool surface did not contain foam or bubbles.

UNKY5A - This curve is a fair-to-good match to the algorithm estimate of 1.750 mm.

UNKY5B - This curve is a fair match to the algorithm estimate of 1.950 mm.

UNKY5C - This curve is a poor match to the algorithm estimate of 2.050 mm. The measured data seems to have a somewhat flat slope and a slightly concave curvature while the estimate has a convex curvature. The result is inconclusive.

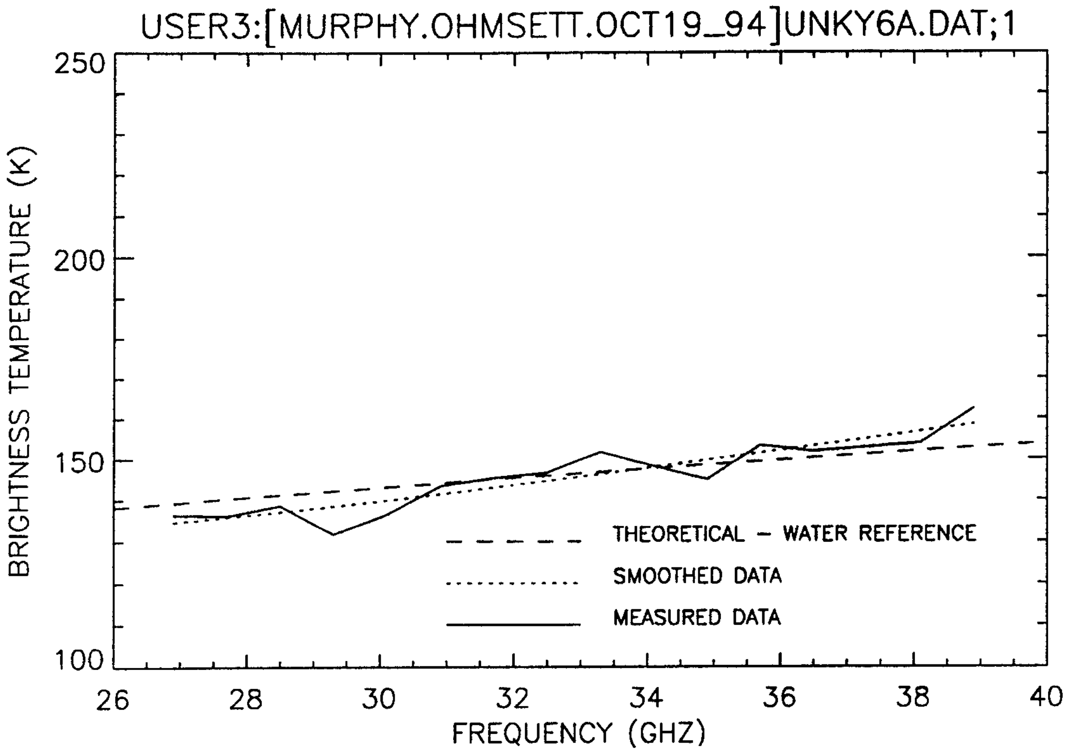

Figure G-89 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, Chop Condition 1, 19 October 1994, Pass 1

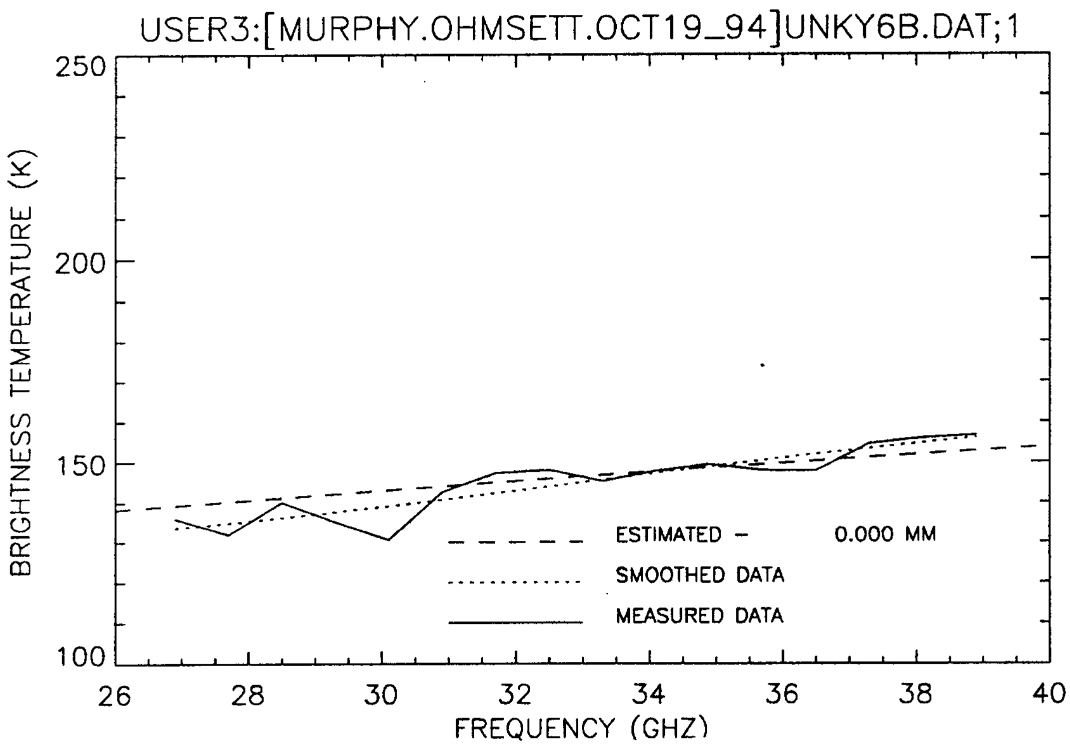

Figure G-90 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, Chop Condition 1, 19 October 1994, Pass 2

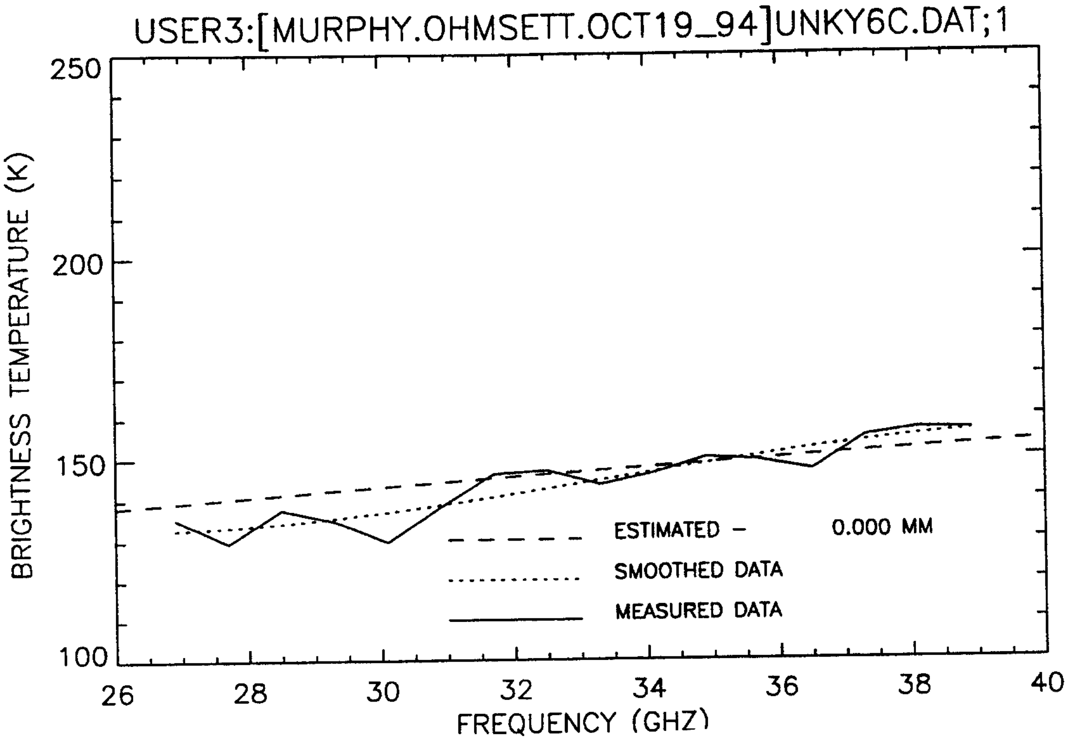

Figure G-91 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, Chop Condition 1, 19 October 1994, Pass 3

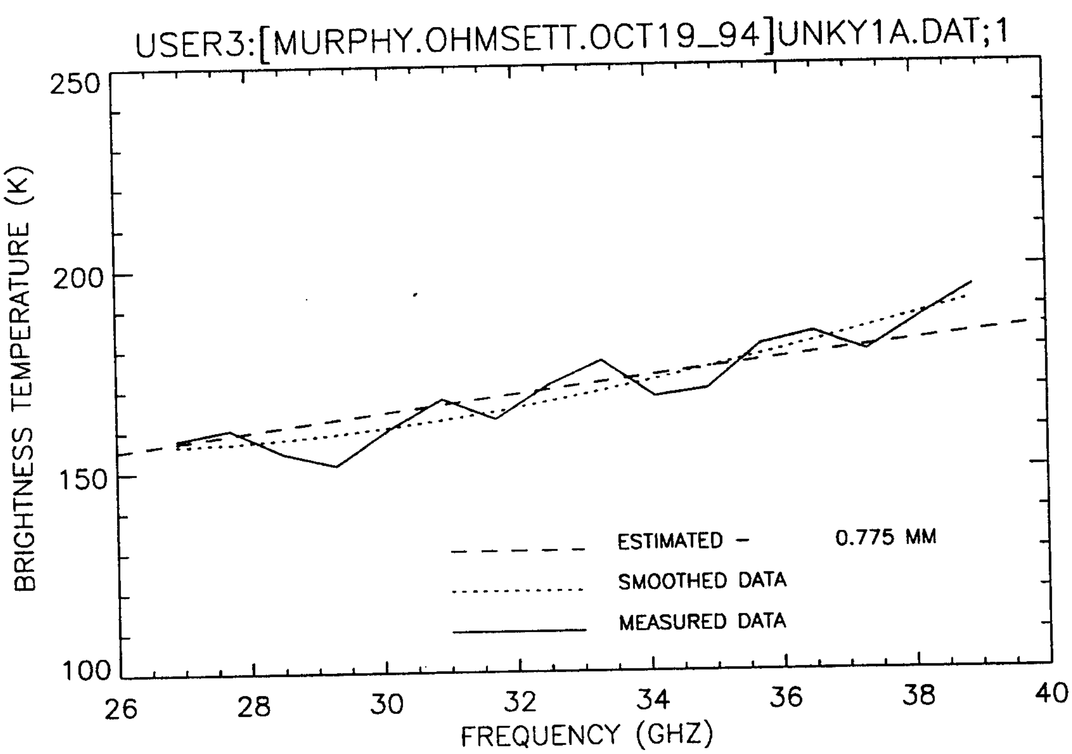

Figure G-92 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Chop Condition 1, 19 October 1994, Pass 1

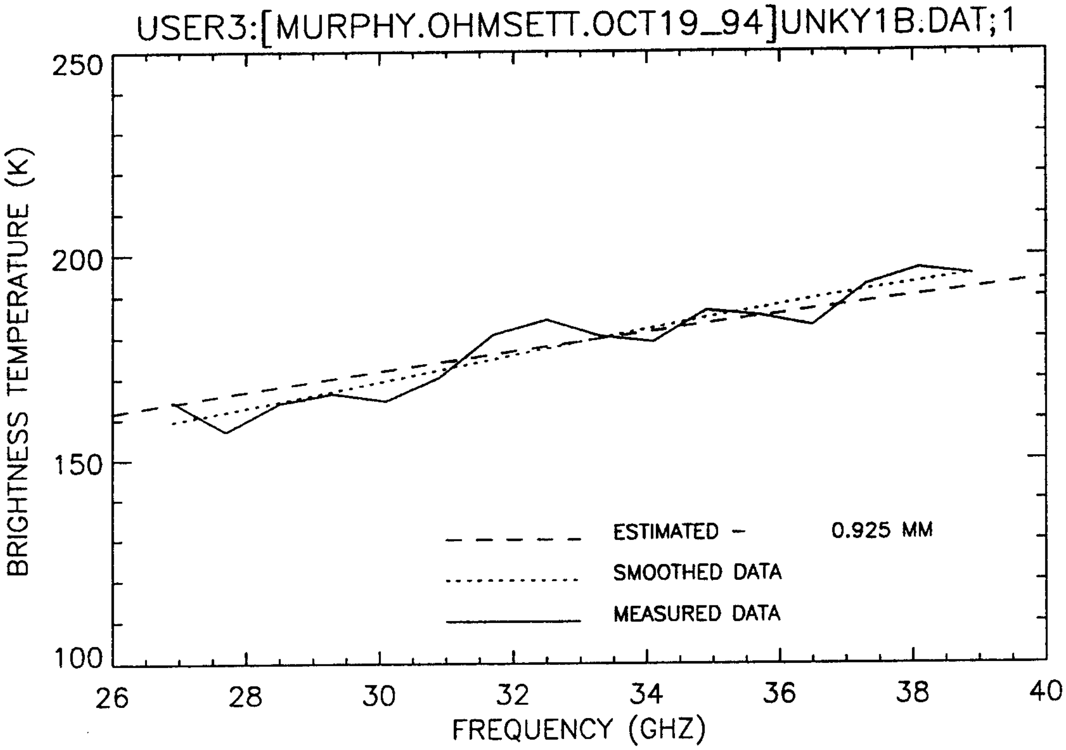

Figure G-93 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Chop Condition 1, 19 October 1994, Pass 2

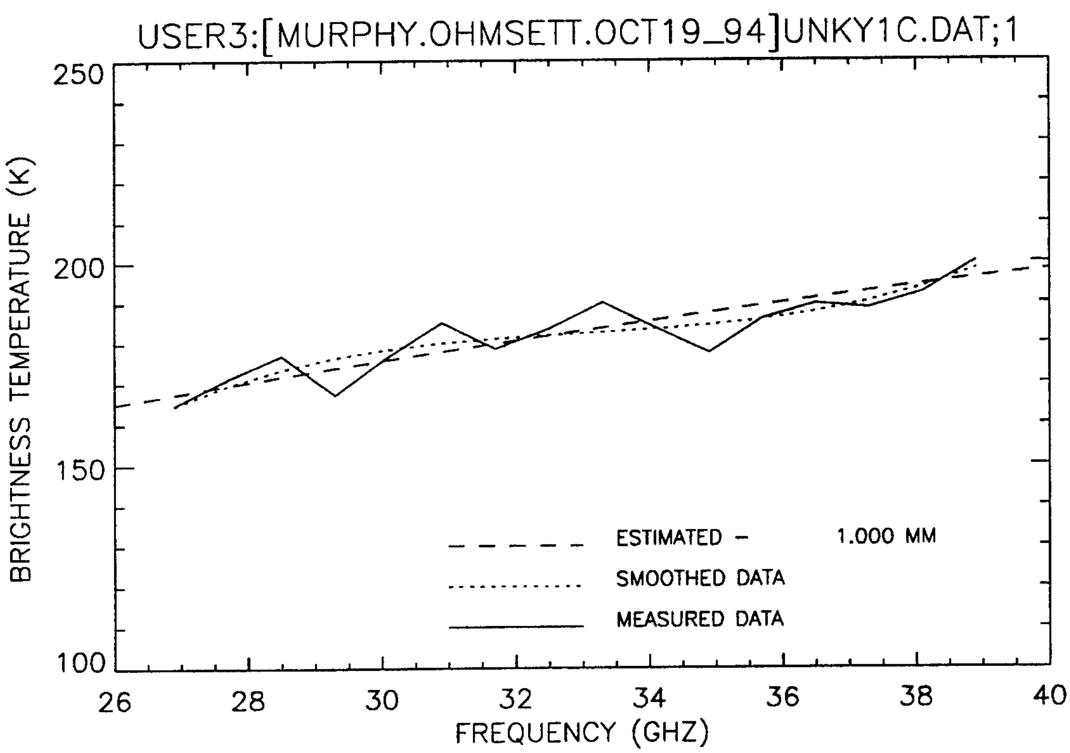

Figure G-94 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Chop Condition 1, 19 October 1994, Pass 3

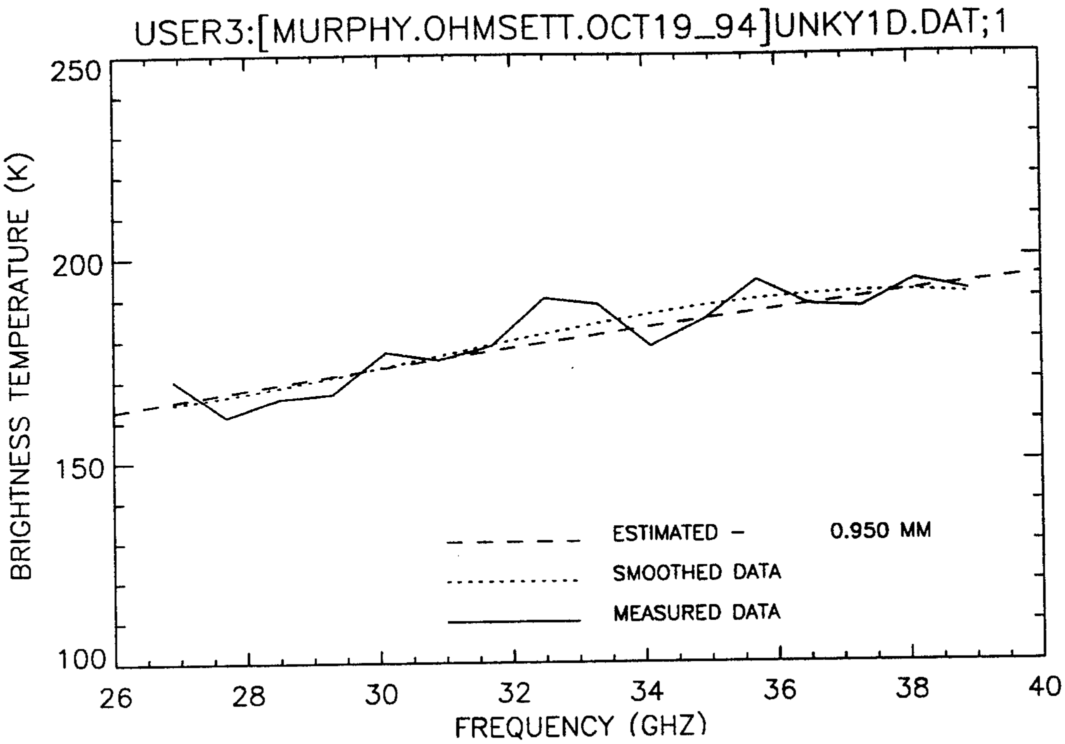

Figure G-95 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Chop Condition 1, 19 October 1994, Pass 4

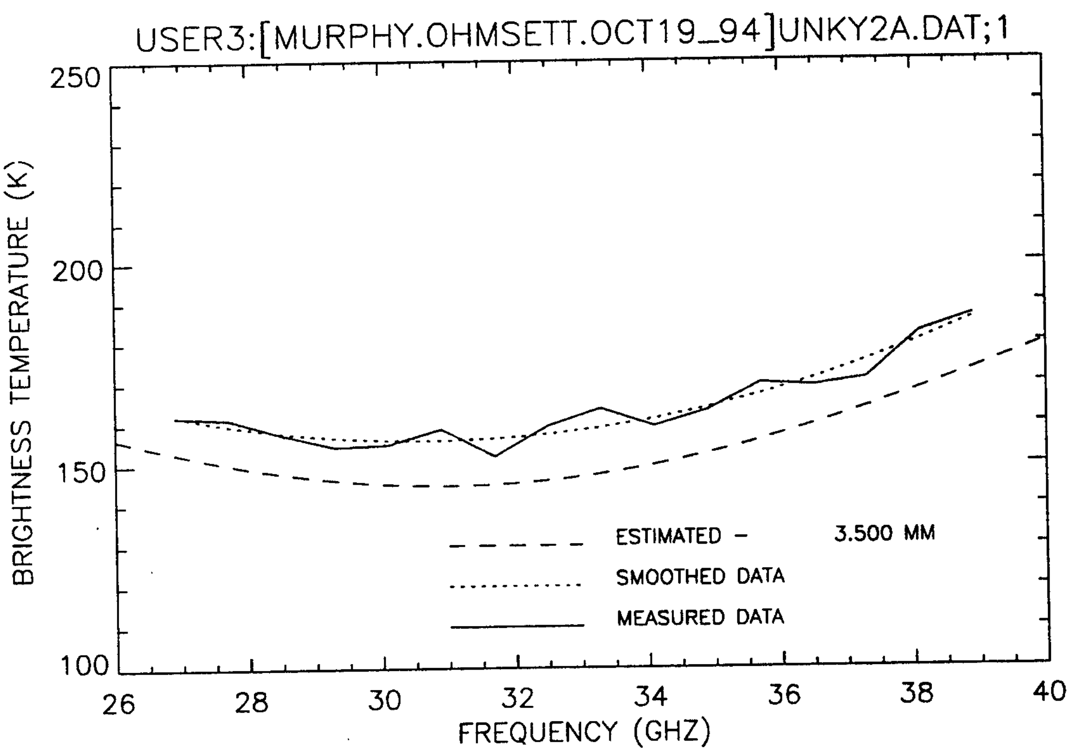

Figure G-96 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, Chop Condition 1, 19 October 1994, Pass 1

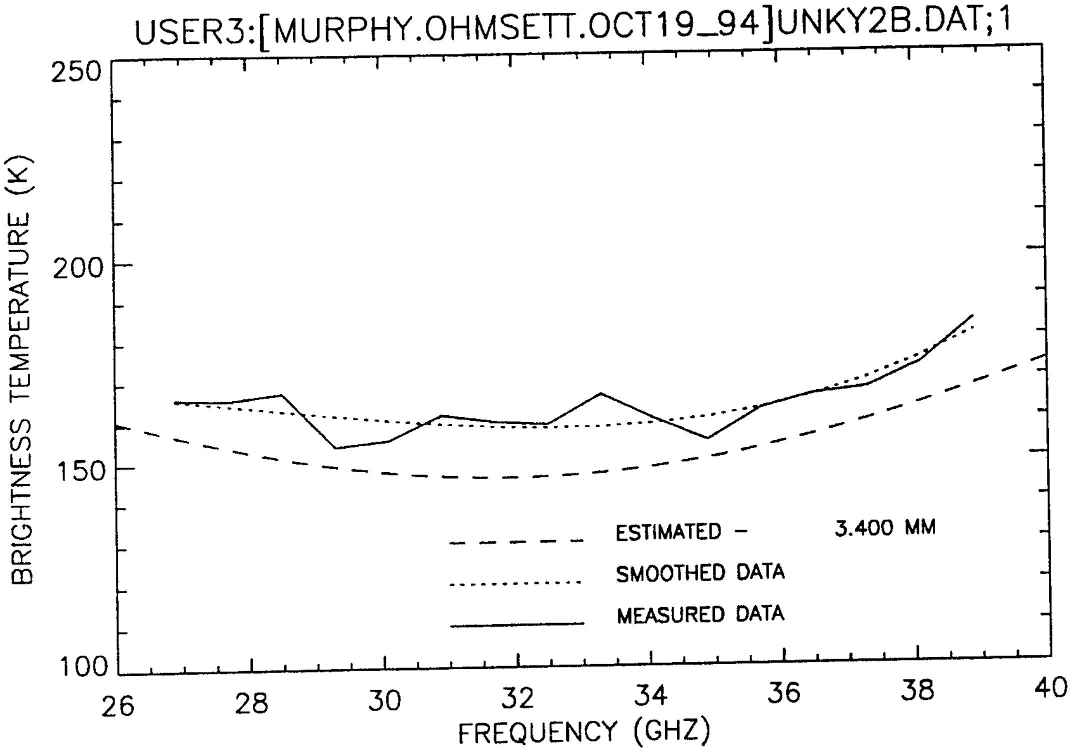

Figure G-97 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, Chop Condition 1, 19 October 1994, Pass 2

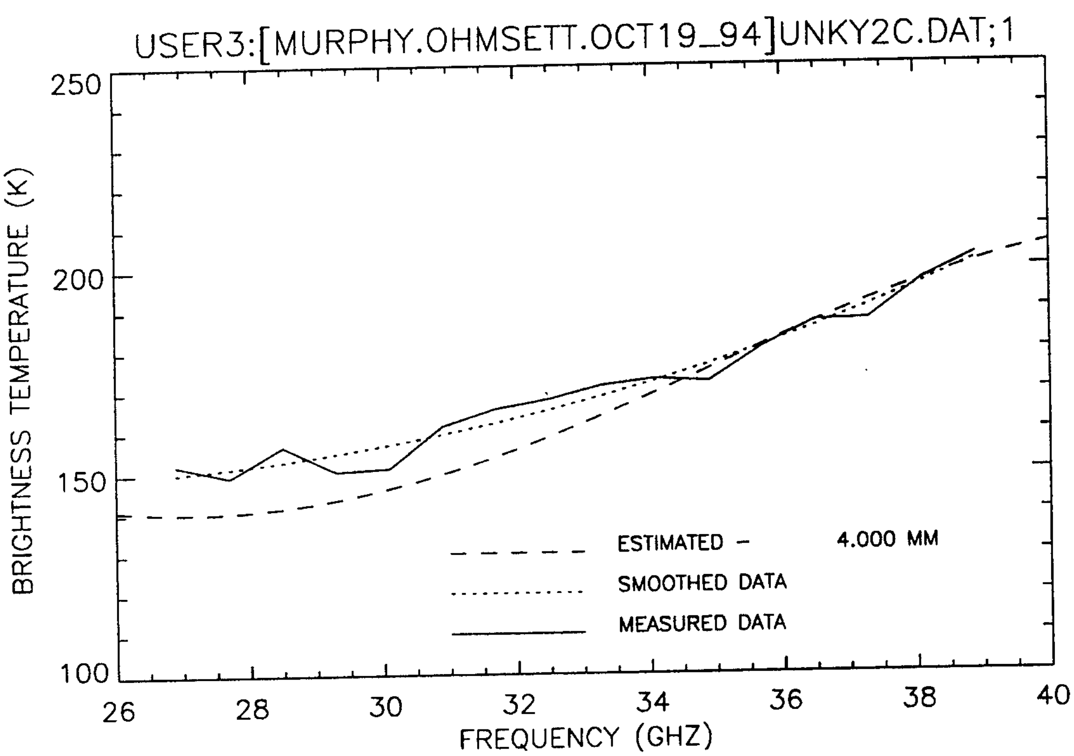

Figure G-98 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, Chop Condition 1, 19 October 1994, Pass 3

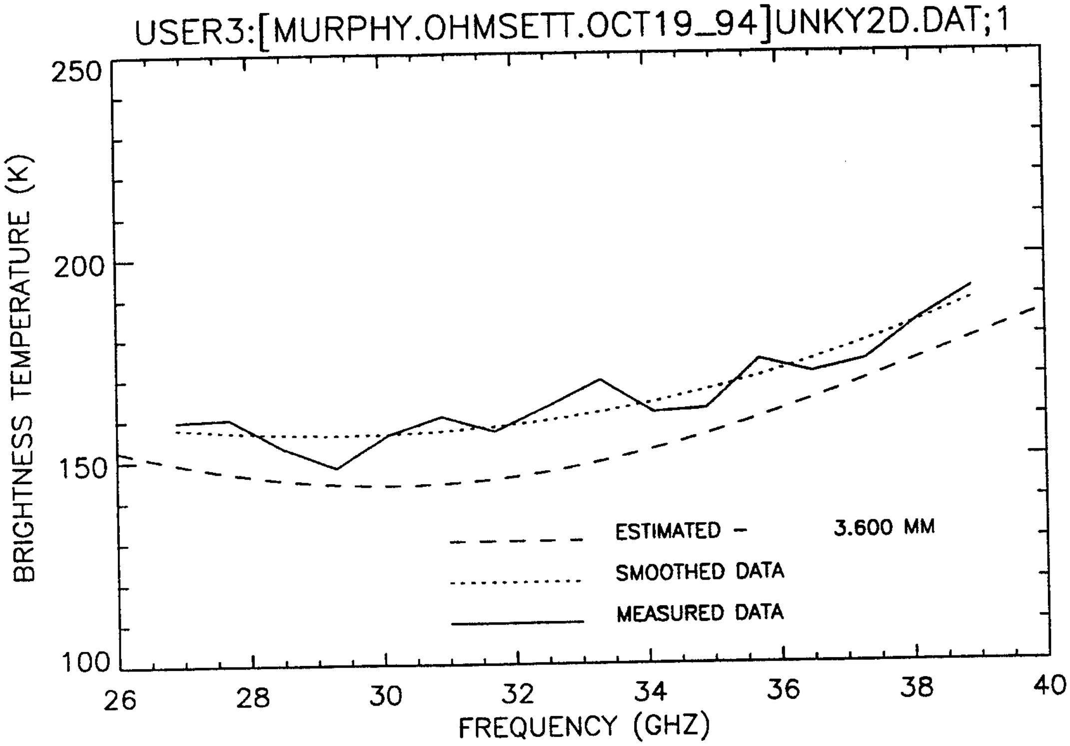

Figure G-99 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, Chop Condition 1, 19 October 1994, Pass 4

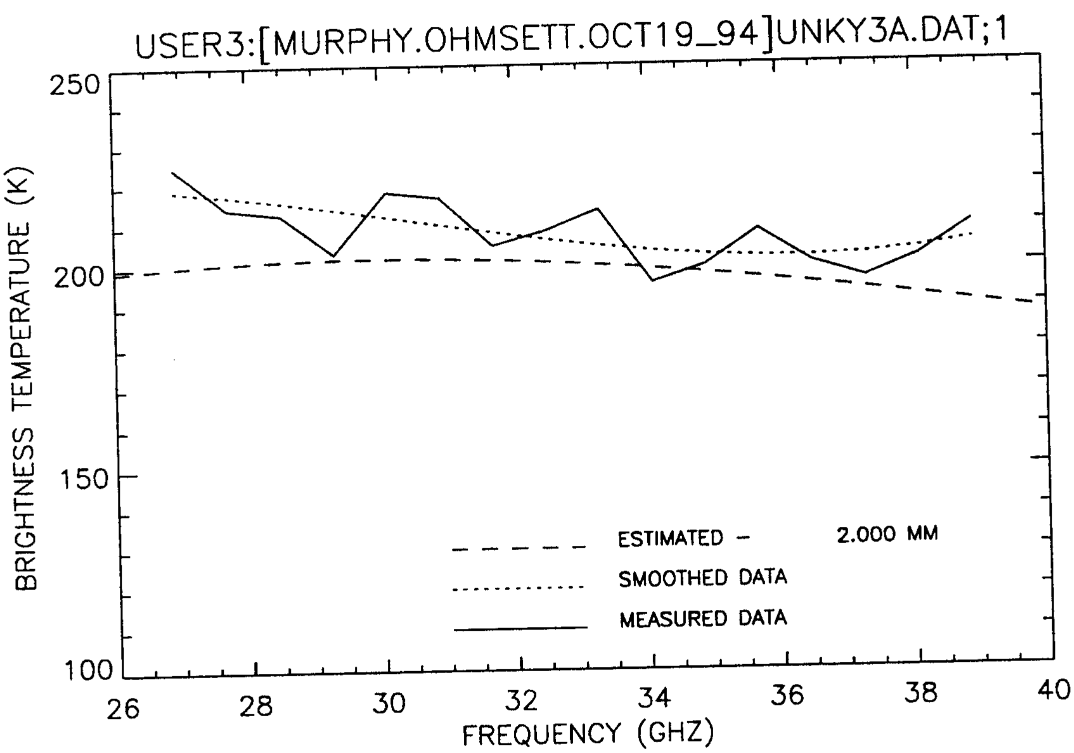

Figure G-100 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, Chop Condition 1, 19 October 1994, Pass 1

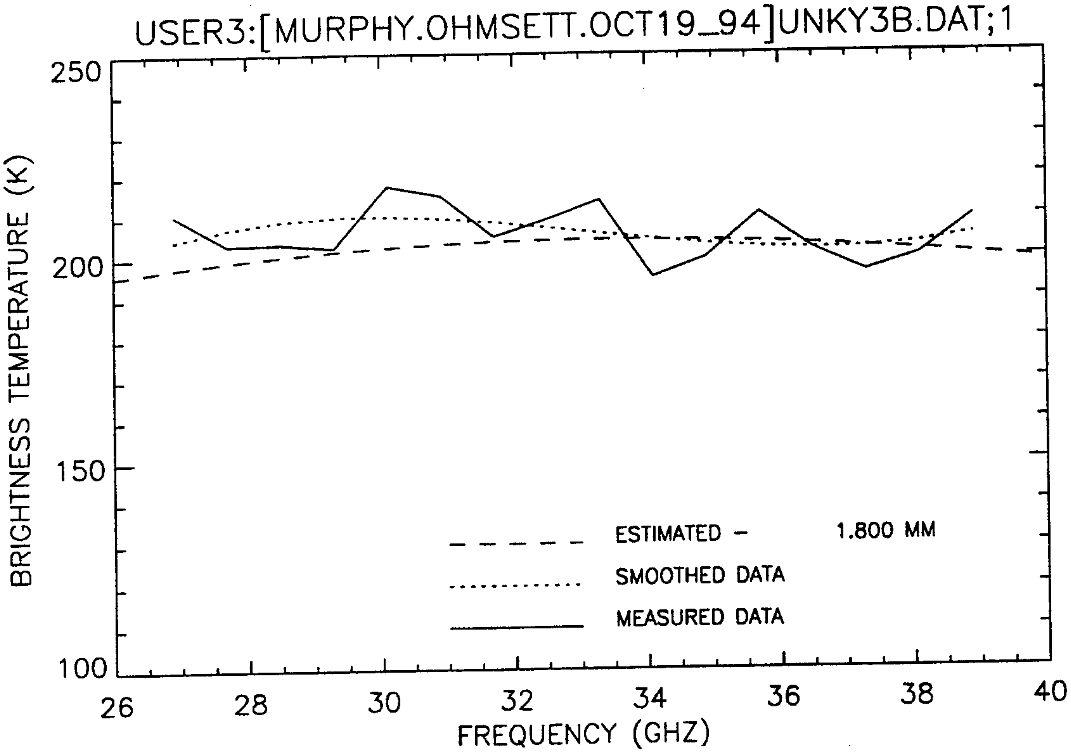

Figure G-101 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, Chop Condition 1, 19 October 1994, Pass 2

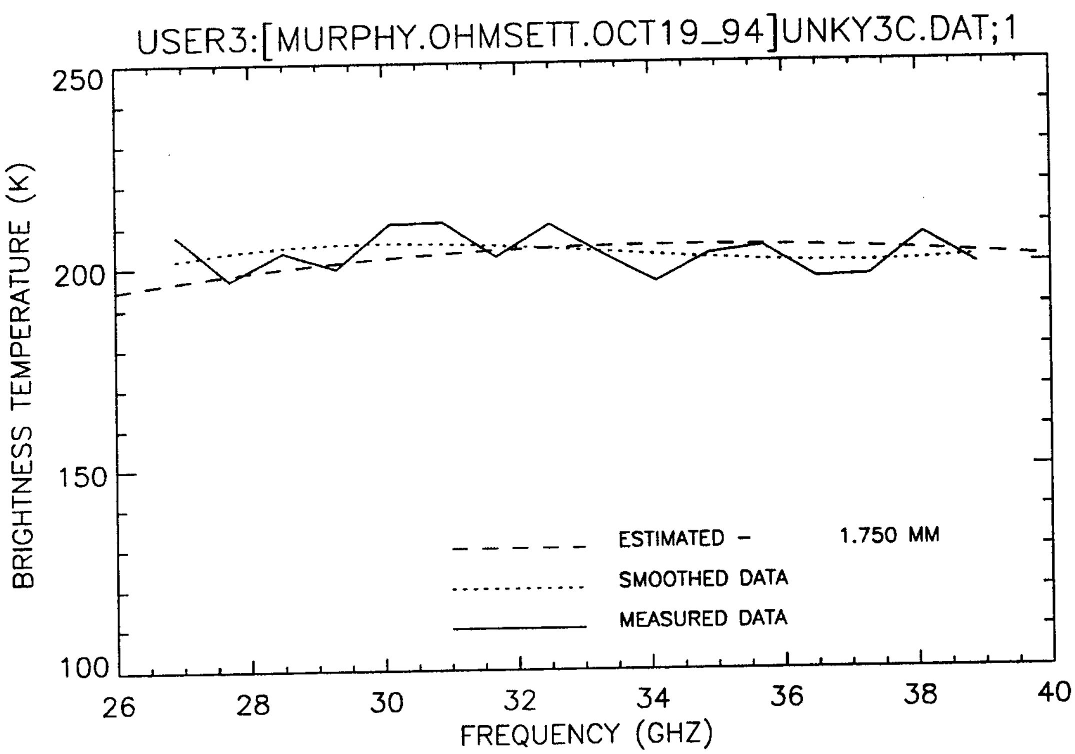

Figure G-102 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, Chop Condition 1, 19 October 1994, Pass 3

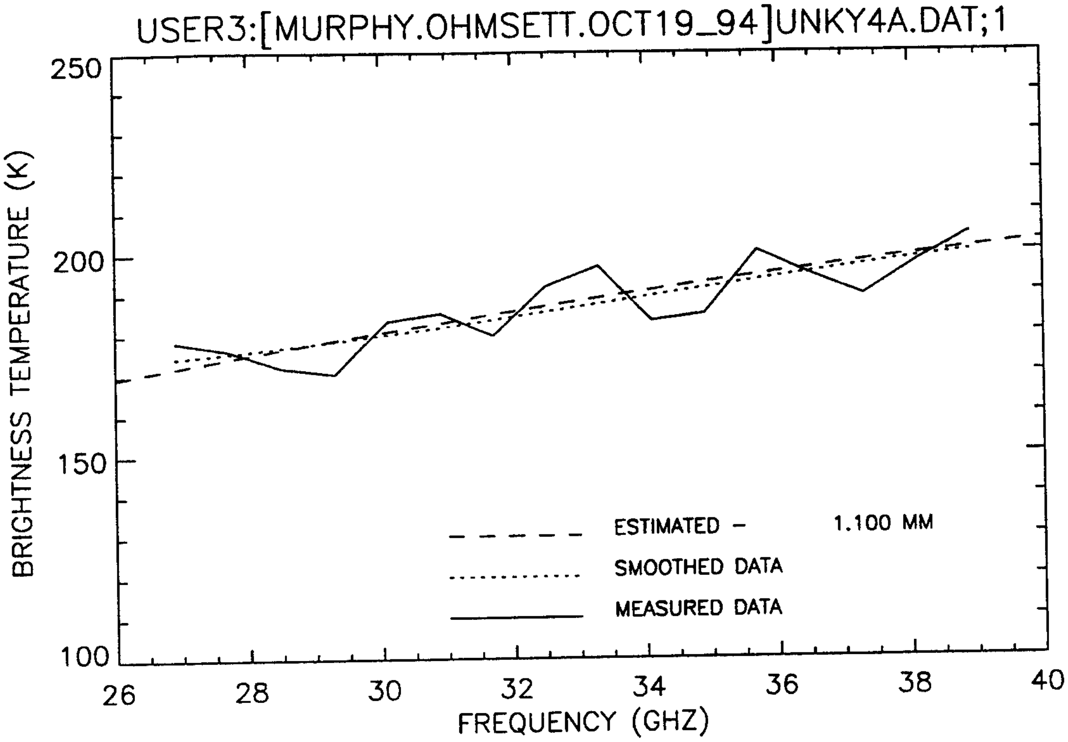

Figure G-103 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Chop Condition 1, 19 October 1994, Pass 1

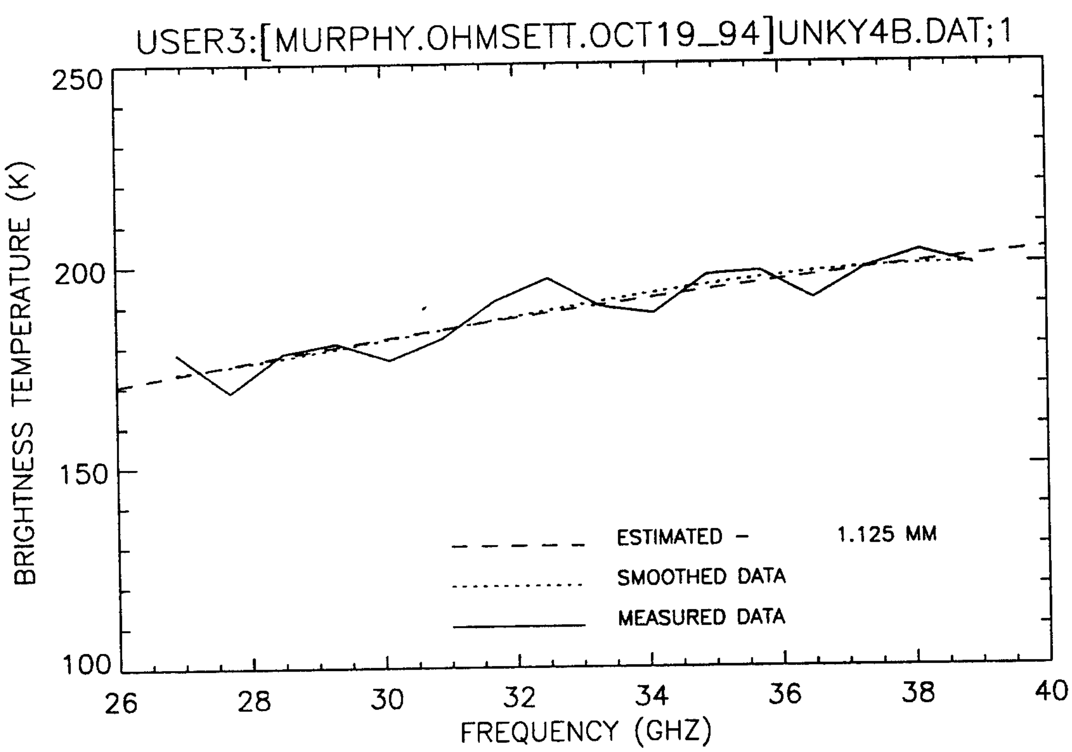

Figure G-104 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Chop Condition 1, 19 October 1994, Pass 2

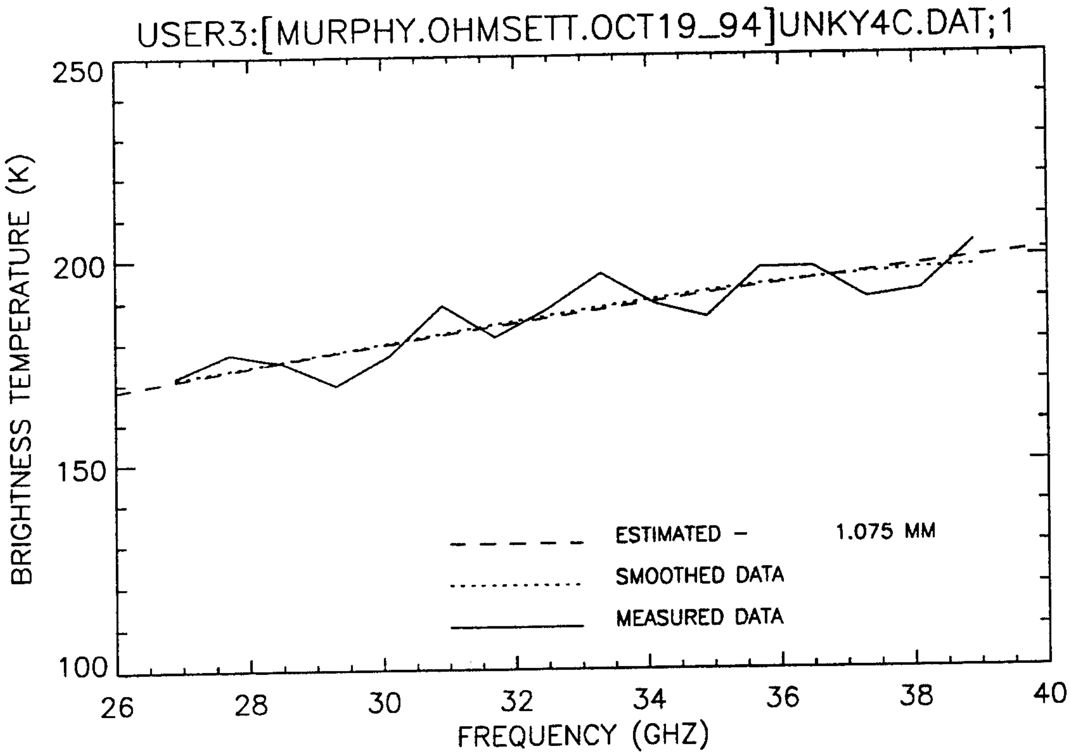

Figure G-105 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Chop Condition 1, 19 October 1994, Pass 3

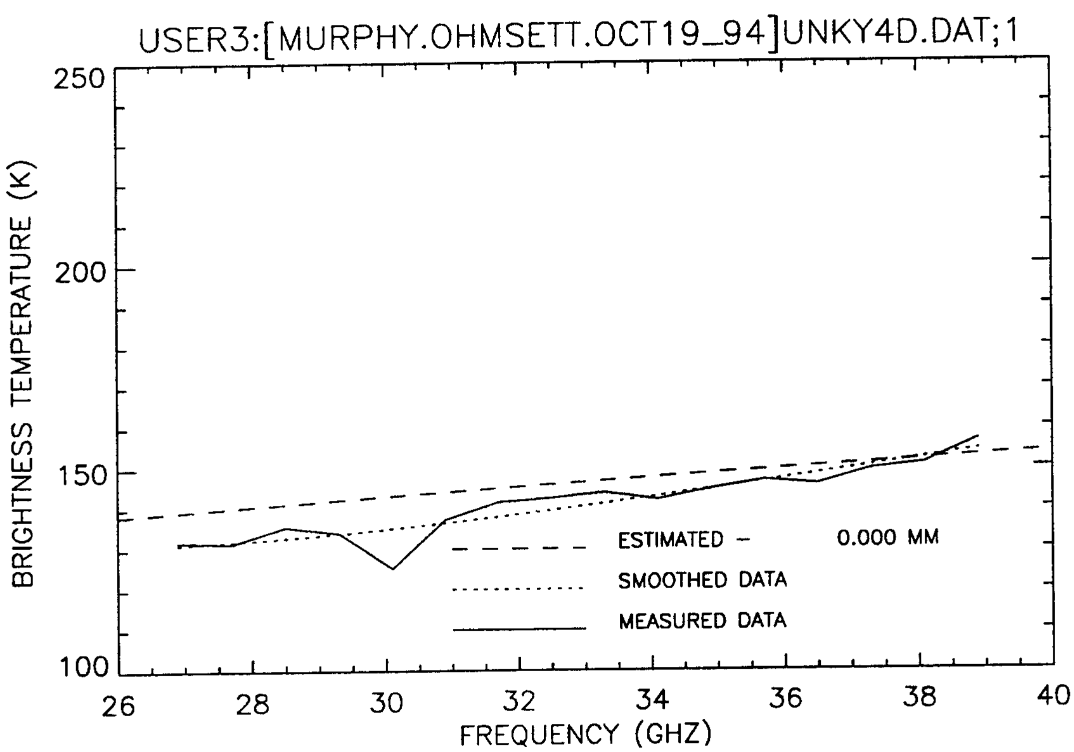

Figure G-106 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Chop Condition 1, 19 October 1994, Pass 4

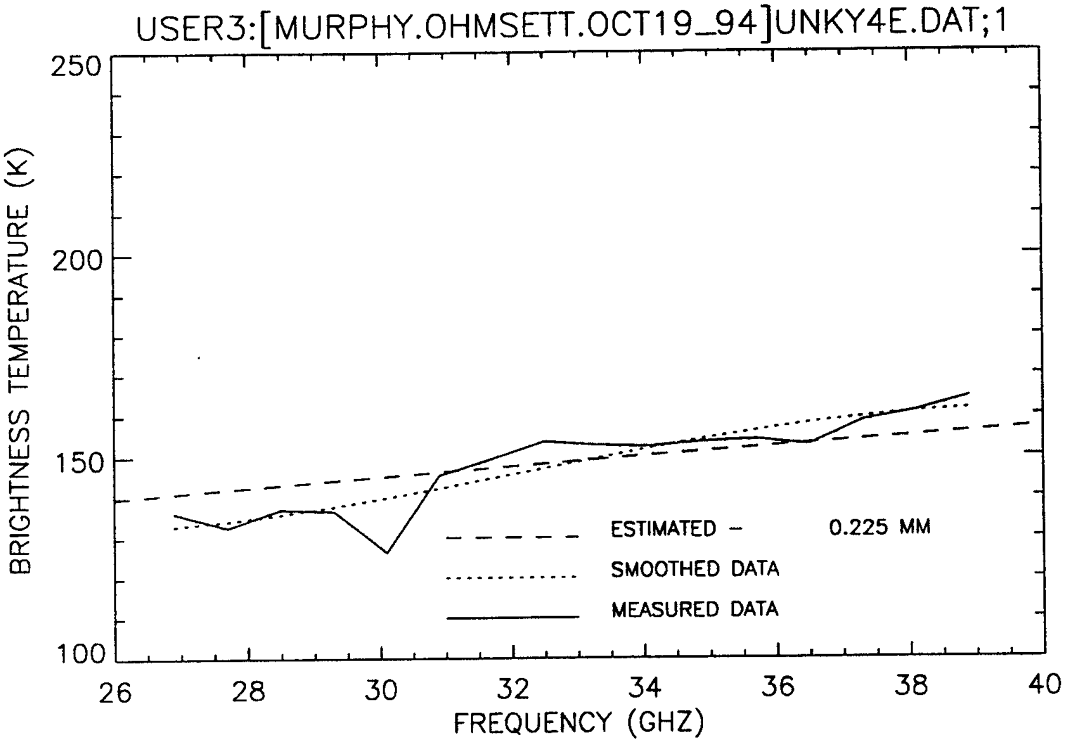

Figure G-107 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Chop Condition 1, 19 October 1994, Pass 5

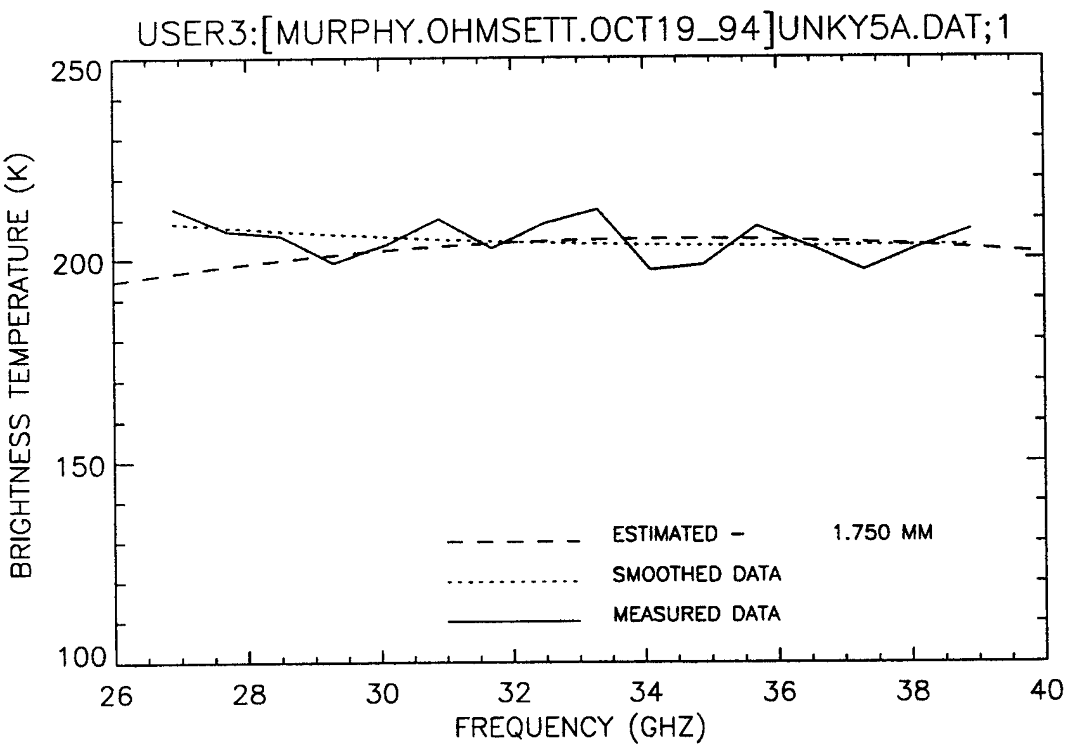

Figure G-108 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, Chop Condition 1, 19 October 1994, Pass 1

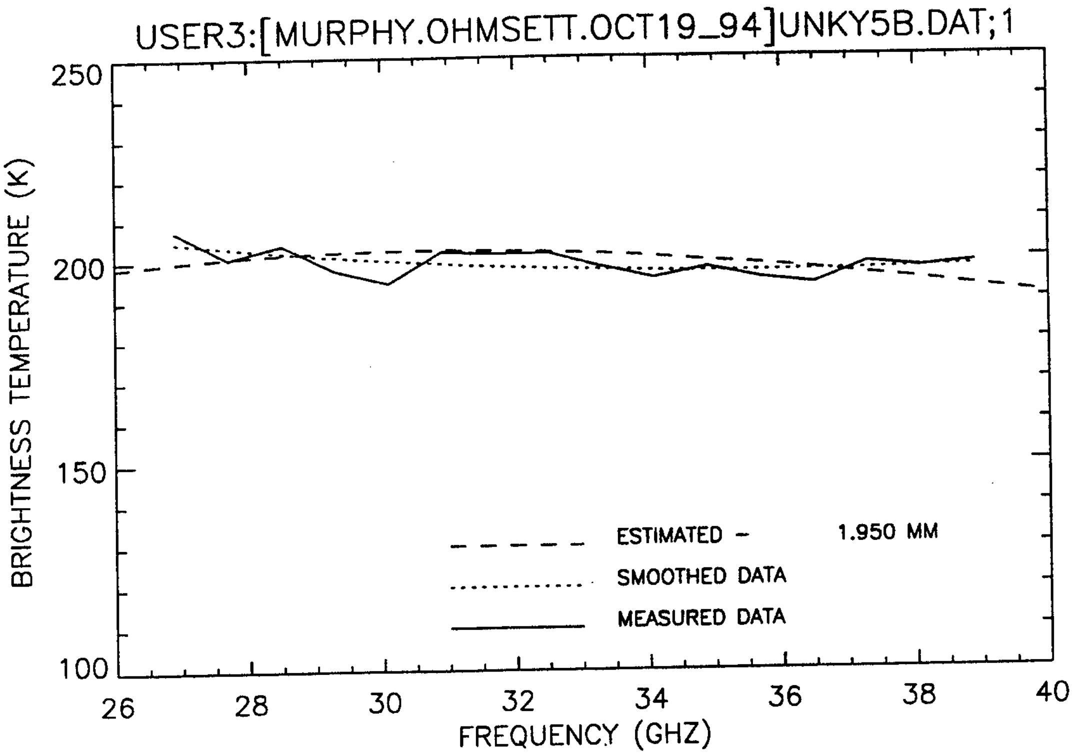

Figure G-109 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, Chop Condition 1, 19 October 1994, Pass 2

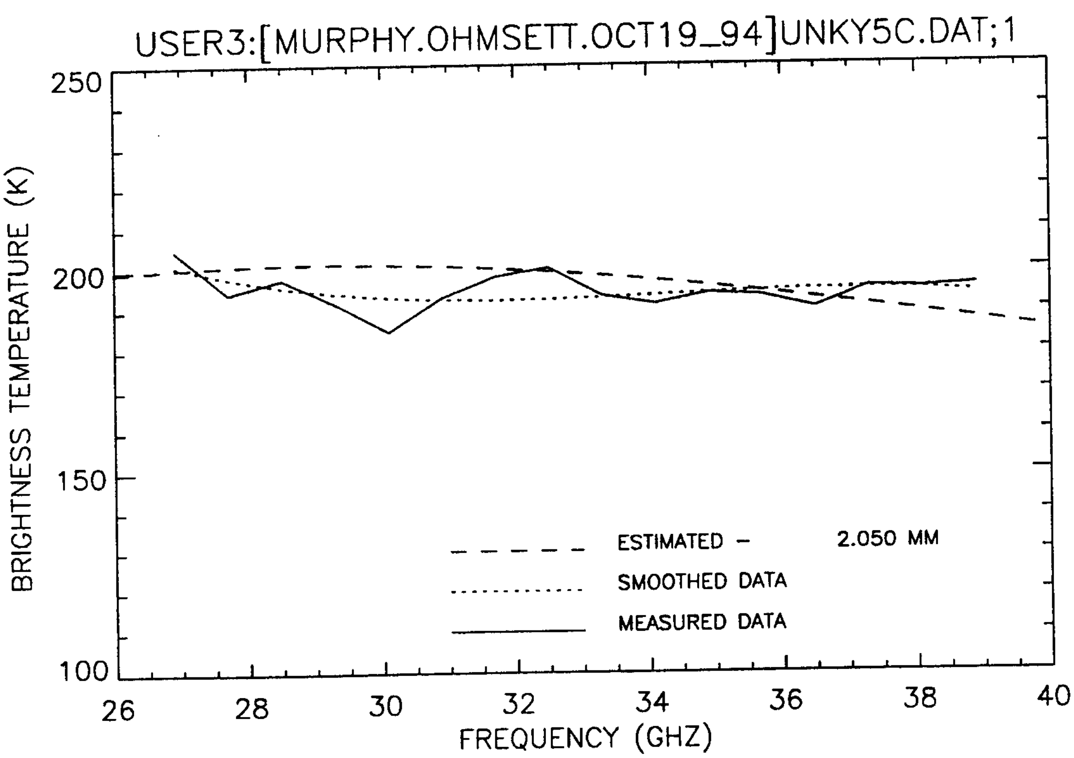

Figure G-110 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, Chop Condition 1, 19 October 1994, Pass 3

The wave generator was reset to provide chop condition 2. Measurements began after the chop condition had reached a steady state.

The water-only pool was used for calibration since some oil had spilled outside of the containment areas. Some small "beads" of oil had infiltrated the water only pool and were in the antenna beam for the next set of measurements. The following measurements were collected from pool 6.

UNKZ6A - This curve was chosen as the background water reference for this data set since it contained the least amount of noise. The noise may be due to sun glint effects.

UNKZ6B - This curve is an excellent match to the algorithm estimate of 0.225 mm. It is assumed that either the small beads of oil in the water reference pool are affecting this measurement, or that sun glint effects are causing noisy measurements, thus raising the level of the background temperature.

UNKZ6C - This curve is a fair match to the algorithm estimate of 0.300 mm. It is assumed that either the small beads of oil in the water reference pool are affecting this measurement, or that sun glint effects are causing noisy measurements, thus raising the level of the background temperature.

The main bridge was positioned for the FSR to measure the center of oil target 1. This target consisted of a 0.74 mm thickness of diesel oil covering 90% of the containment area. The surface of the target contained foam and/or bubbles.

UNKZ1A - This curve is a poor match to the algorithm estimate of 1.675 mm. The shape of the measured curve matches a 2.0 mm estimate (plotted); however, the overall high T^B indicates the presence of bubbles or an emulsion.

UNKZ1B - This curve is a poor match to the algorithm estimate of 1.700 mm. The shape of the measured curve matches a 2.0 mm estimate (plotted); however, the overall high T^B indicates the presence of bubbles or an emulsion.

UNKZ1C - This curve is a poor match to the algorithm estimate of 1.675 mm. The shape of the measured curve matches a 2.0 mm estimate (plotted);

however, the overall high T^B indicates the presence of bubbles or an emulsion.

The main bridge was positioned for the FSR to measure the center of oil target 2. This target consisted of a 2.6 mm thickness of diesel oil covering the entire containment area. This pool contained more foam/bubbles on the oil surface than any other oil target pool.

UNKZ2A - This curve is a poor match to the algorithm estimate of 1.675 mm. The shape of the measured curve matches a 1.9 mm estimate (plotted); however, the overall high T^B indicates the presence of bubbles or an emulsion.

UNKZ2B - This curve is a poor match to the algorithm estimate of 1.675 mm. The shape of the measured curve matches a 1.9 mm estimate (plotted); however, the overall high T^B indicates the presence of bubbles or an emulsion.

UNKZ2C - This curve is a poor match to the algorithm estimate of 1.675 mm. The shape of the measured curve matches the estimate; however, the overall high T^B indicates the presence of bubbles or an emulsion.

The main bridge was positioned for the FSR to measure the center of oil target 3. This target consisted of a 2.0 mm thickness of a mixture of 75% diesel oil and 25% crude oil that covered the entire containment area. There were many small air or water bubbles in the oil target surface.

UNKZ3A - This curve is a poor match to the algorithm estimate of 1.675 mm. The shape of the measured curve seems to match the correlation estimate of 4.1 mm (plotted); however, the overall high T^B indicates the presence of bubbles or an emulsion.

UNKZ3B - This curve is a poor match to the algorithm estimate of 1.650 mm. The overall high T^B indicates the presence of bubbles or an emulsion.

UNKZ3C - This curve is a poor match to the algorithm estimate of 1.675 mm. The shape of the measured curve matches a 1.8 mm estimate (plotted); however, the overall high T^B indicates the presence of bubbles or an emulsion.

The main bridge was positioned for the FSR to measure the center of oil target 4. This target consisted of a 1.7 mm thickness of a mixture of 50% diesel oil and 50% waste oil covering 60% of the surface of the containment area. Just prior to the first measurement sweep, a wave broke over the surface of the oil target. The surface contained air and water bubbles.

UNKZ4A - This curve is a poor match to the algorithm estimate of 1.675 mm. The shape of the measured curve matches a 1.9 mm estimate (plotted); however, the overall high T^B indicates the presence of bubbles or an emulsion.

UNKZ4B - This curve is a poor match to the algorithm estimate of 1.675 mm. The shape of the measured curve somewhat resembles a 1.9 mm estimate (plotted); however, the overall high T^B indicates the presence of bubbles or an emulsion.

UNKZ4C - This curve is a poor match to the algorithm estimate of 1.675 mm. The shape of the measured curve matches the estimate; however, the overall high T^B indicates the presence of bubbles or an emulsion.

The main bridge was positioned for the FSR to measure the center of oil target 5. This target consisted of a 2.5 mm thickness of a mixture of 75% diesel oil and 25% waste oil that covered the entire containment area. The surface of this target had entrapped air or water bubbles.

UNKZ5A - This curve is a poor match to the algorithm estimate of 1.675 mm. The shape of the measured curve somewhat matches the estimate; however, the overáll high T^B indicates the presence of bubbles or an emulsion.

UNKZ5B - This curve is a poor match to the algorithm estimate of 1.675 mm. The shape of the measured curve matches the estimate but the data are noisy. The overall high T^B indicates the presence of bubbles or an emulsion.

UNKZ5A - This curve is a poor match to the algorithm estimate of 1.675 mm. The overall high T^B indicates the presence of bubbles or an emulsion.

Based on the similarities of all of the measurements analyzed for this chop 2 wave condition, it would appear that the presence of foam or bubbles seems to create a high and somewhat flat T^B response.

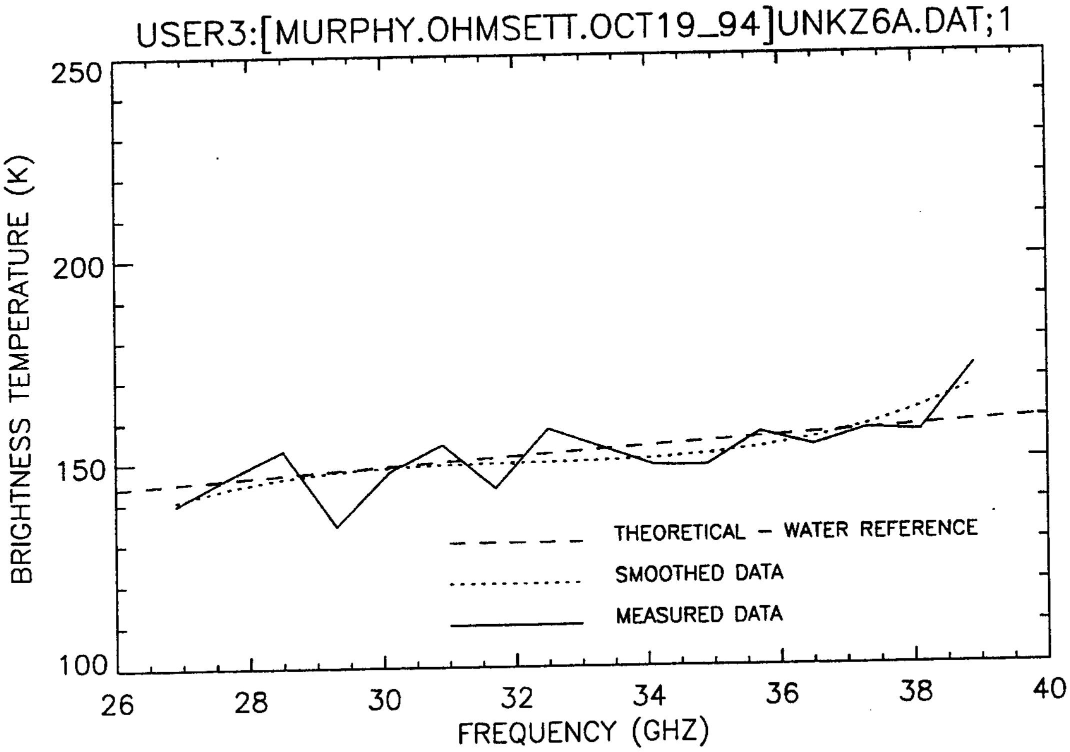

Figure G-111 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, Chop Condition 2, 19 October 1994, Pass 1

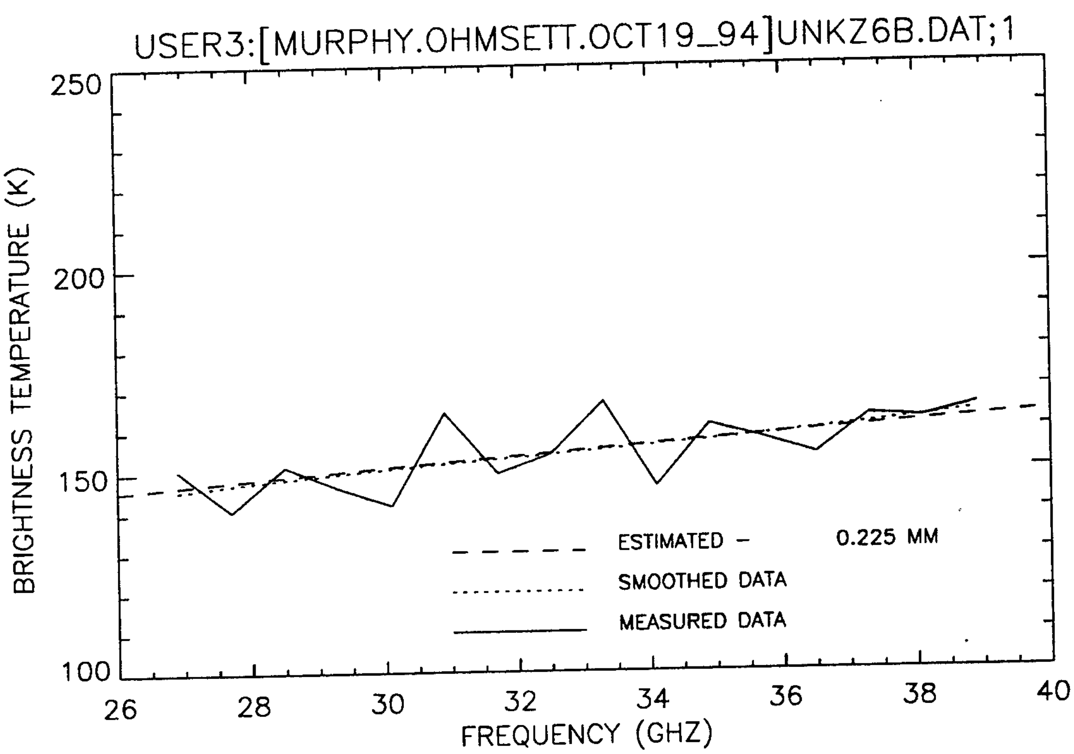

Figure G-112 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, Chop Condition 2, 19 October 1994, Pass 2

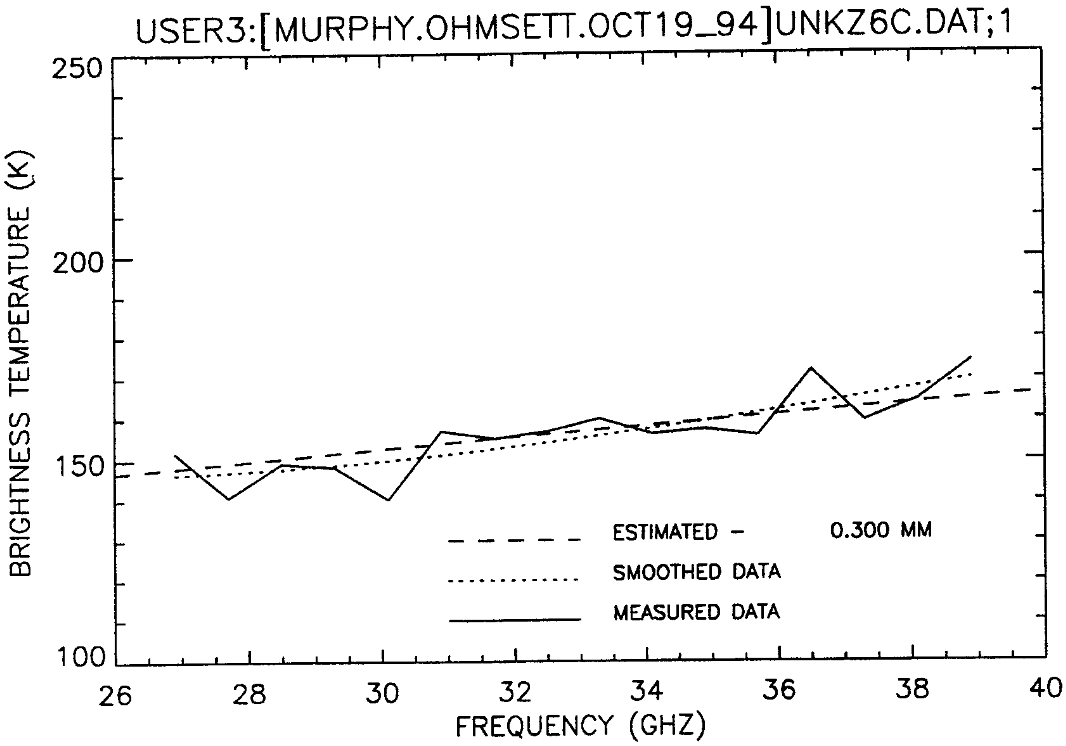

Figure G-113 T^B Versus Frequency Plot for Background Water, "Unknowns" Measurement, Chop Condition 2, 19 October 1994, Pass 3

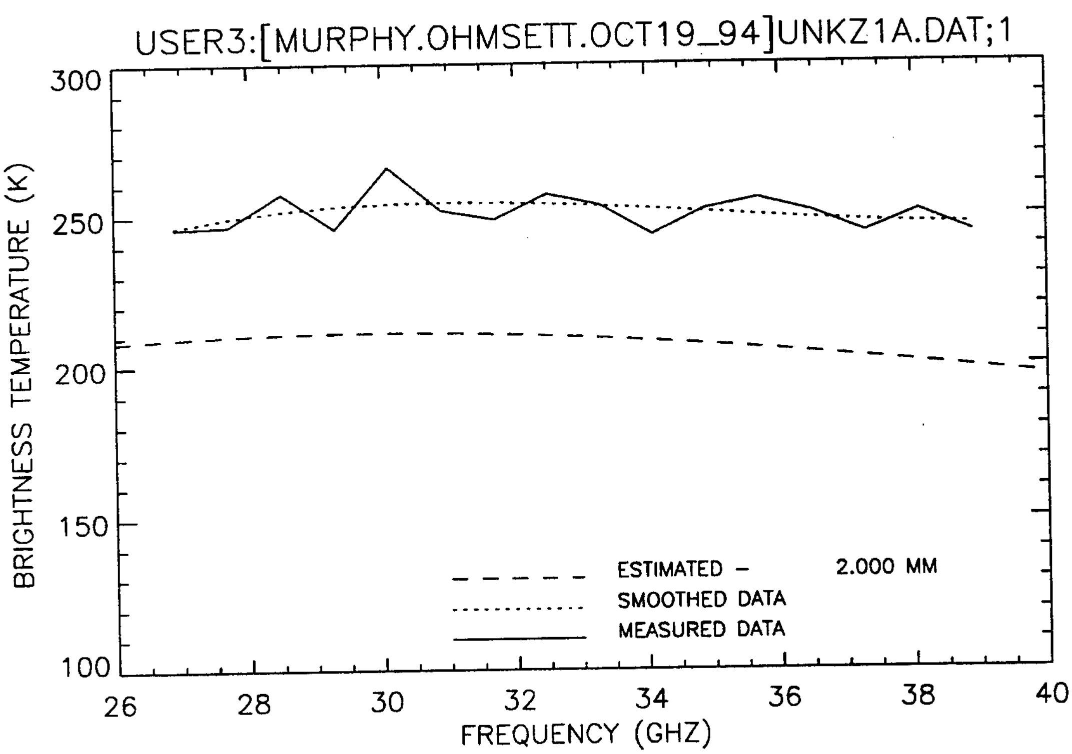

Figure G-114 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Chop Condition 2, 19 October 1994, Pass 1

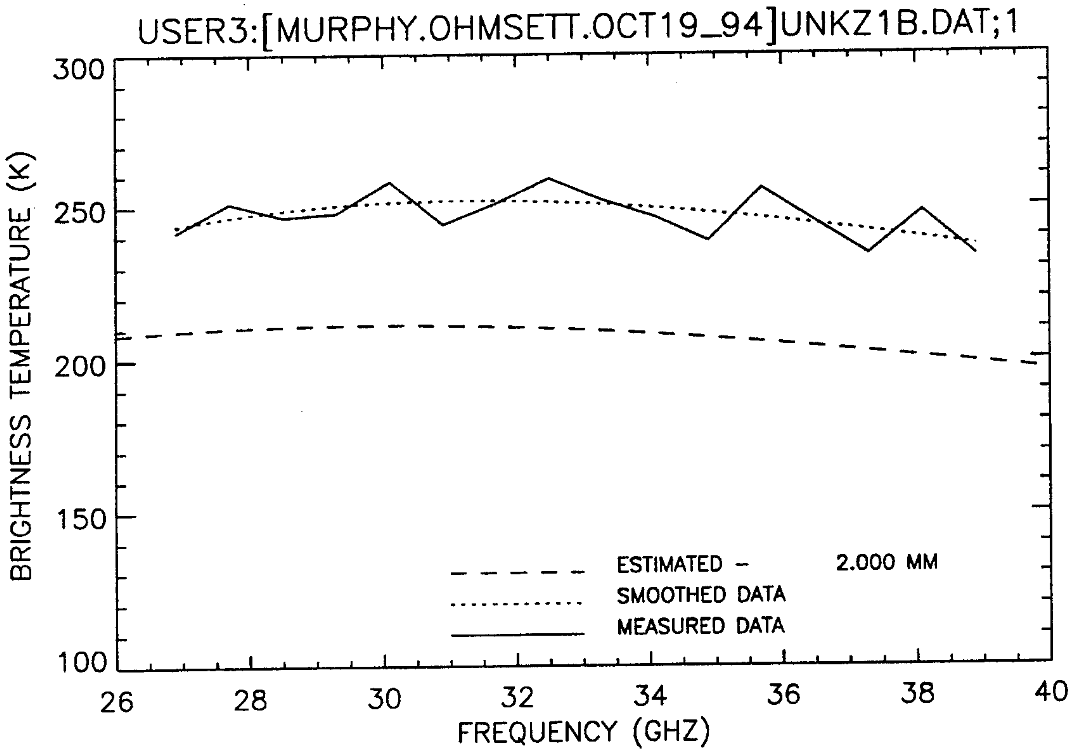

Figure G-115 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Chop Condition 2, 19 October 1994, Pass 2

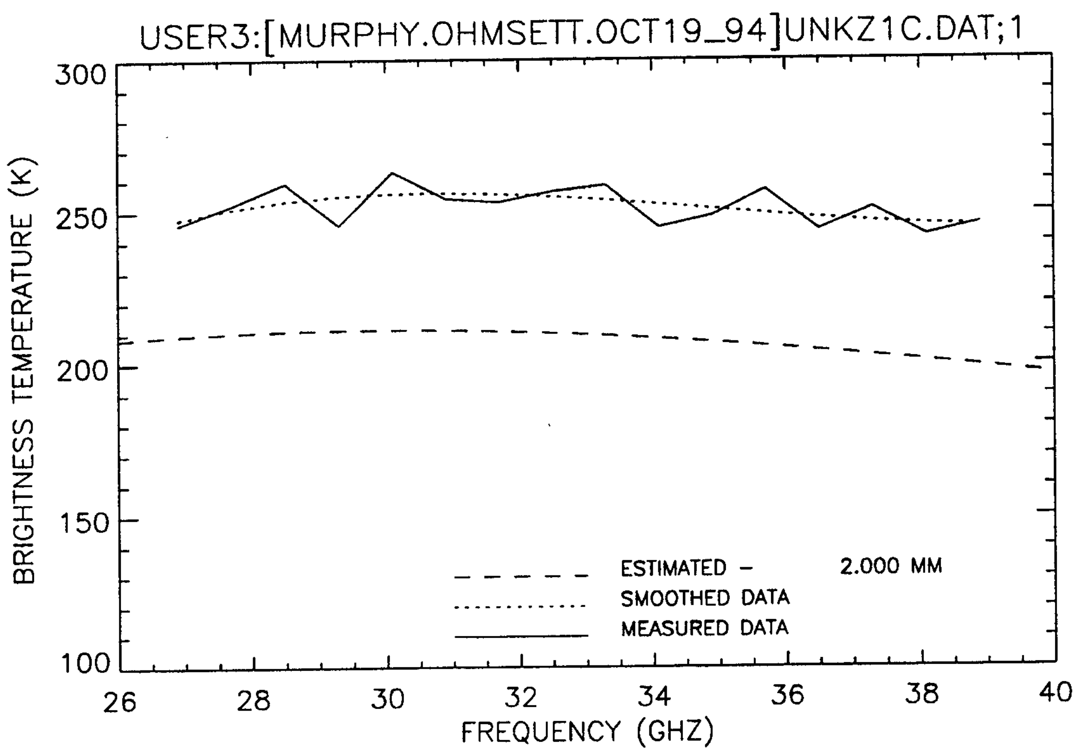

Figure G-116 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 1, Chop Condition 2, 19 October 1994, Pass 3

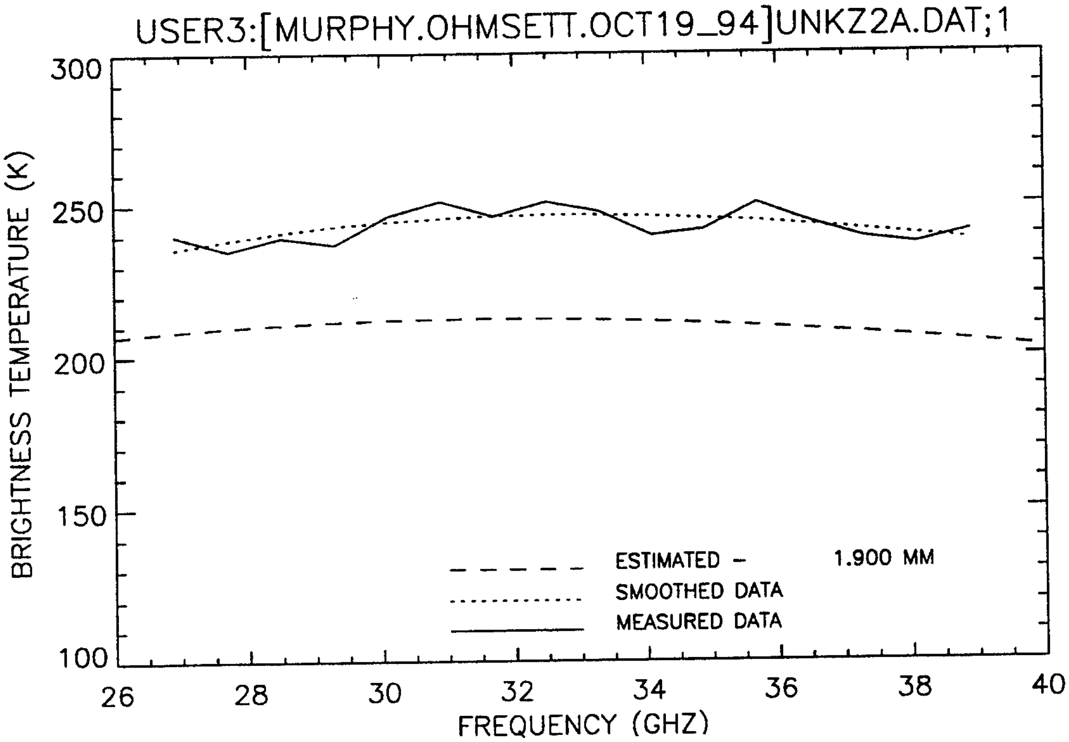

Figure G-117 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, Chop Condition 2, 19 October 1994, Pass 1

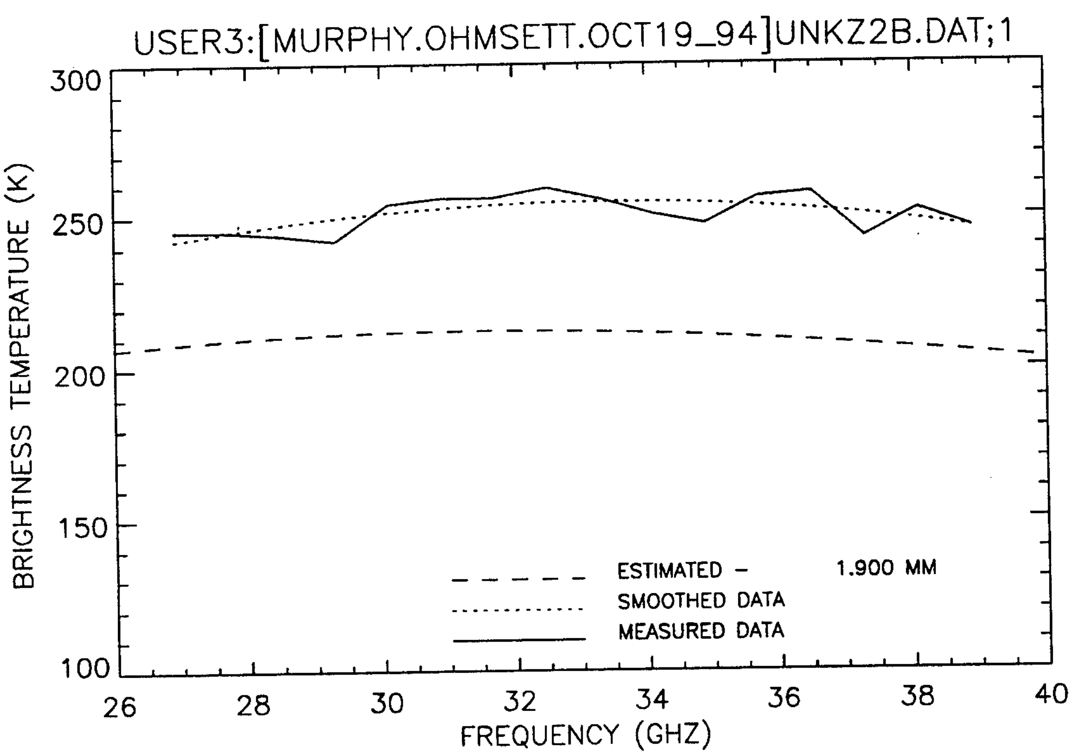

Figure G-118 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, Chop Condition 2, 19 October 1994, Pass 2

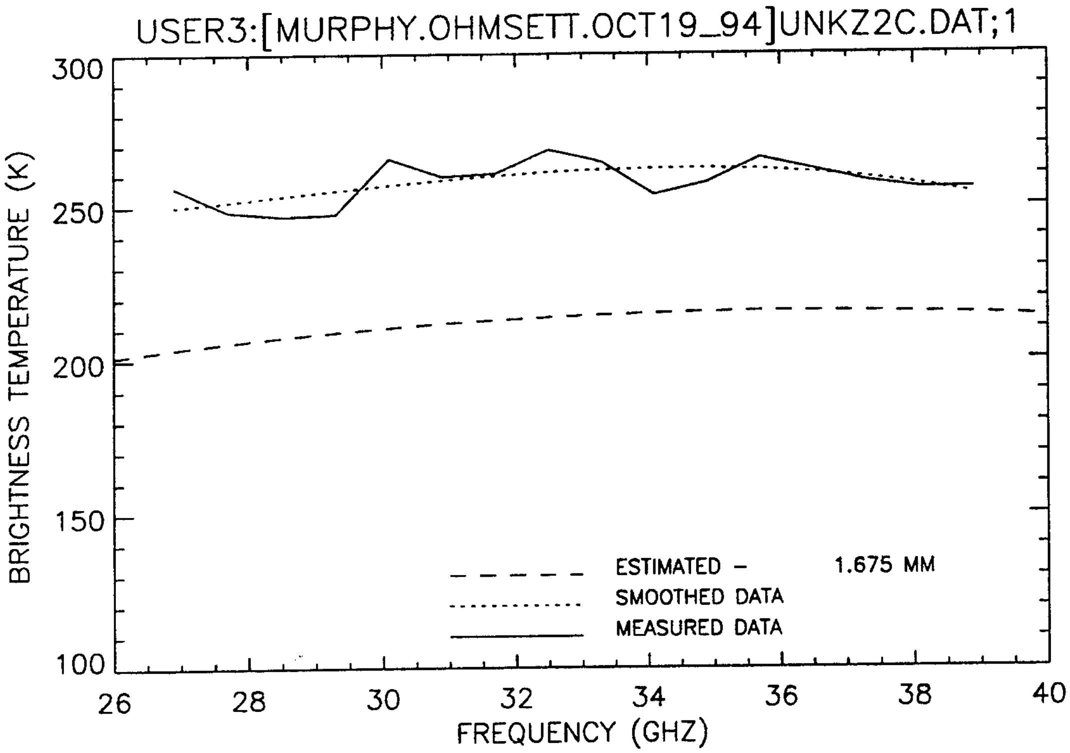

Figure G-119 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 2, Chop Condition 2, 19 October 1994, Pass 3

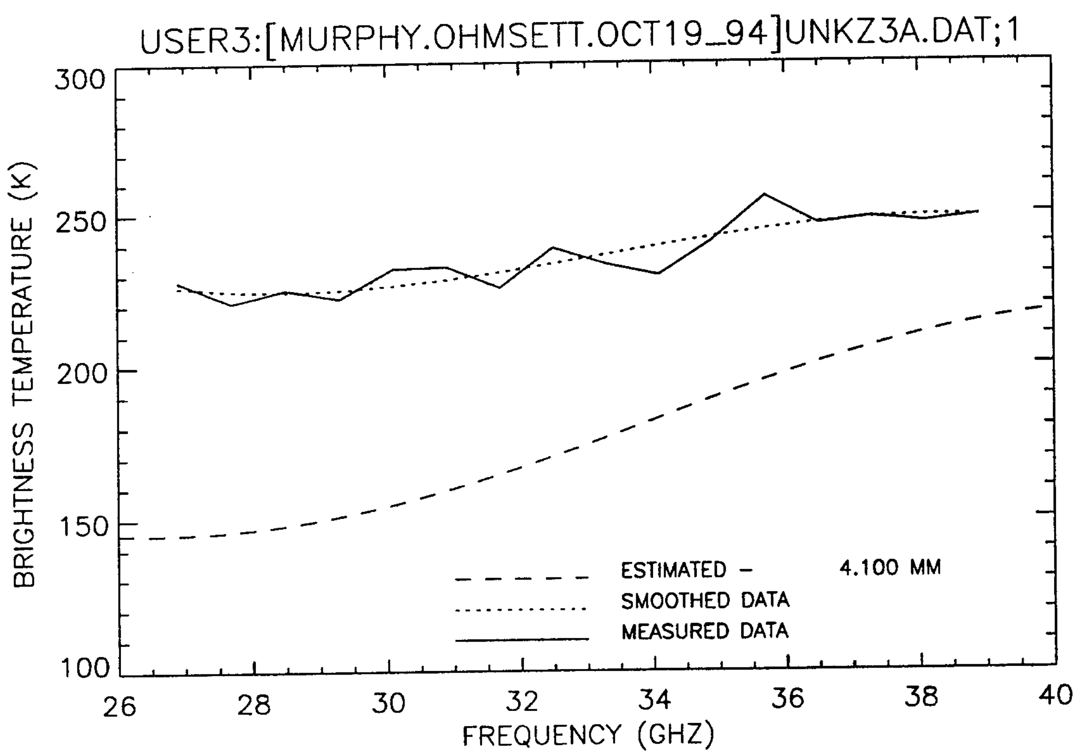

Figure G-120 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, Chop Condition 2, 19 October 1994, Pass 1

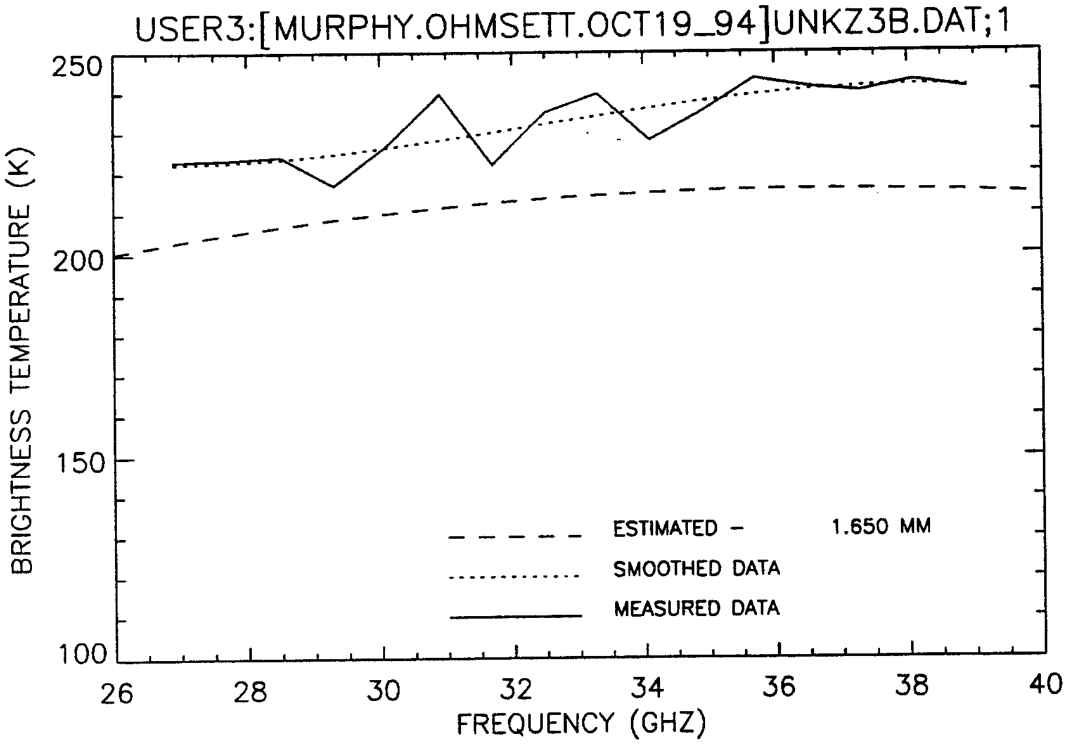

Figure G-121 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, Chop Condition 2, 19 October 1994, Pass 2

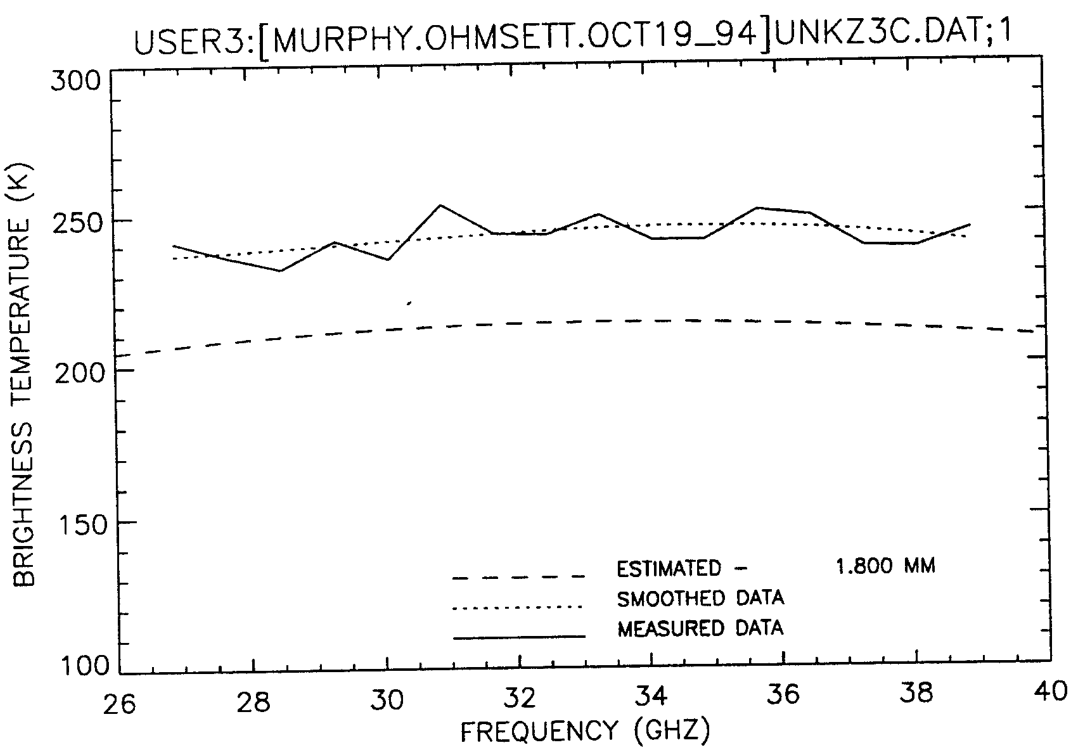

Figure G-122 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 3, Chop Condition 2, 19 October 1994, Pass 3

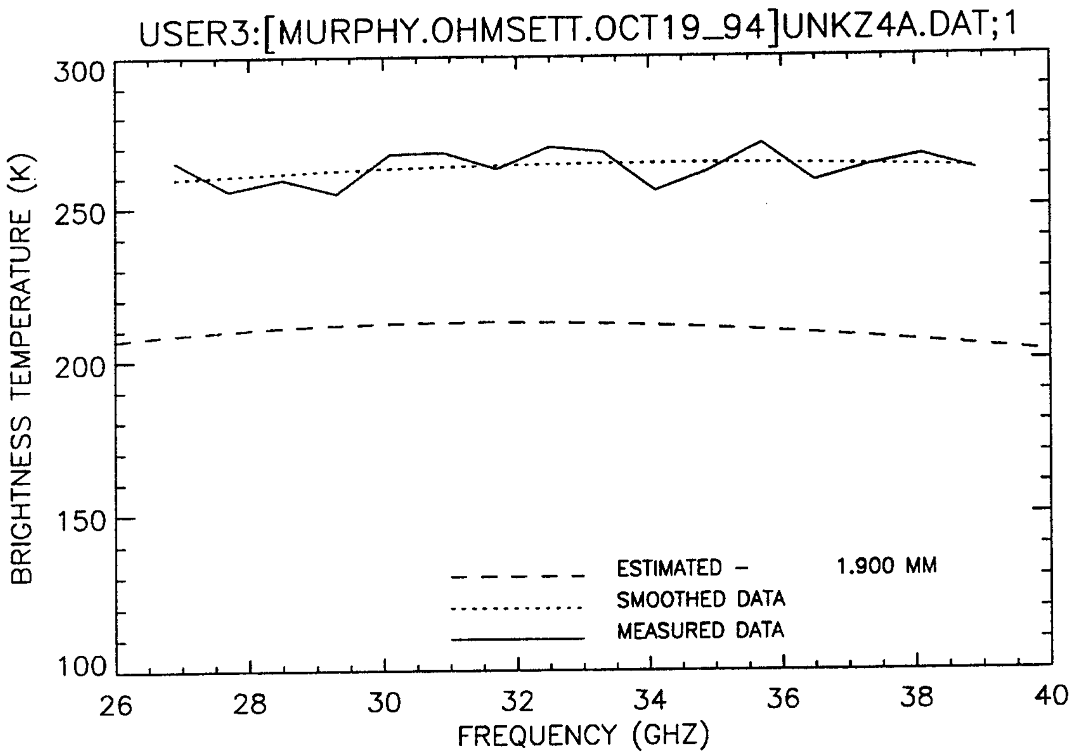

Figure G-123 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Chop Condition 2, 19 October 1994, Pass 1

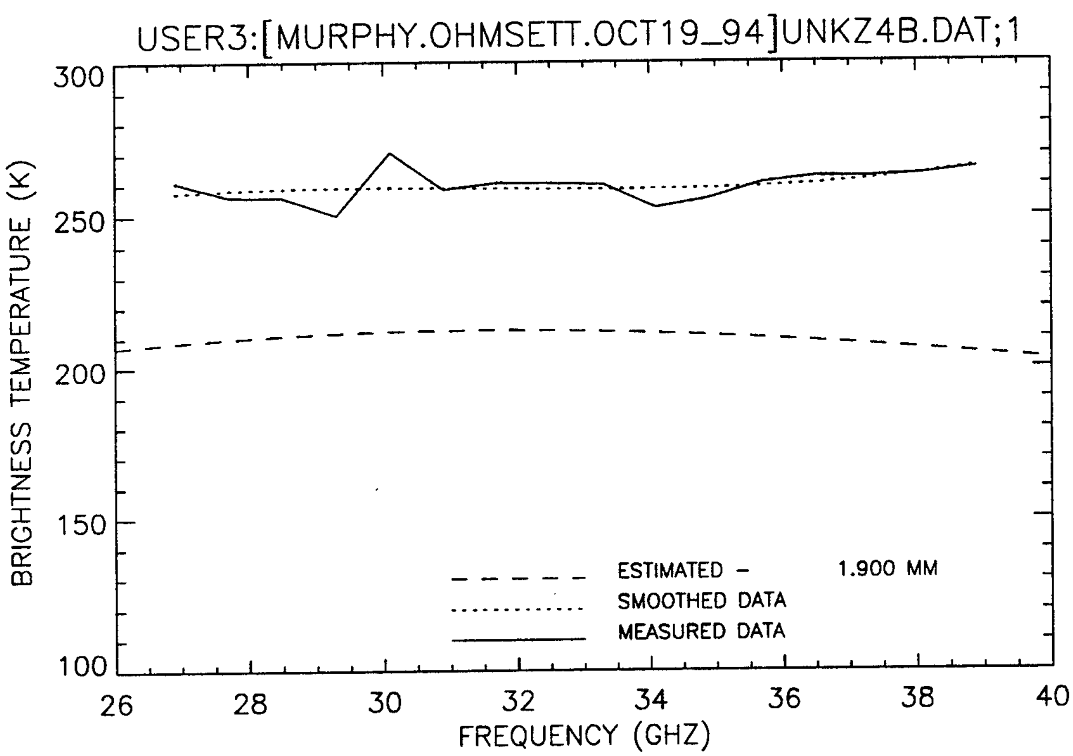

Figure G-124 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Chop Condition 2, 19 October 1994, Pass 2

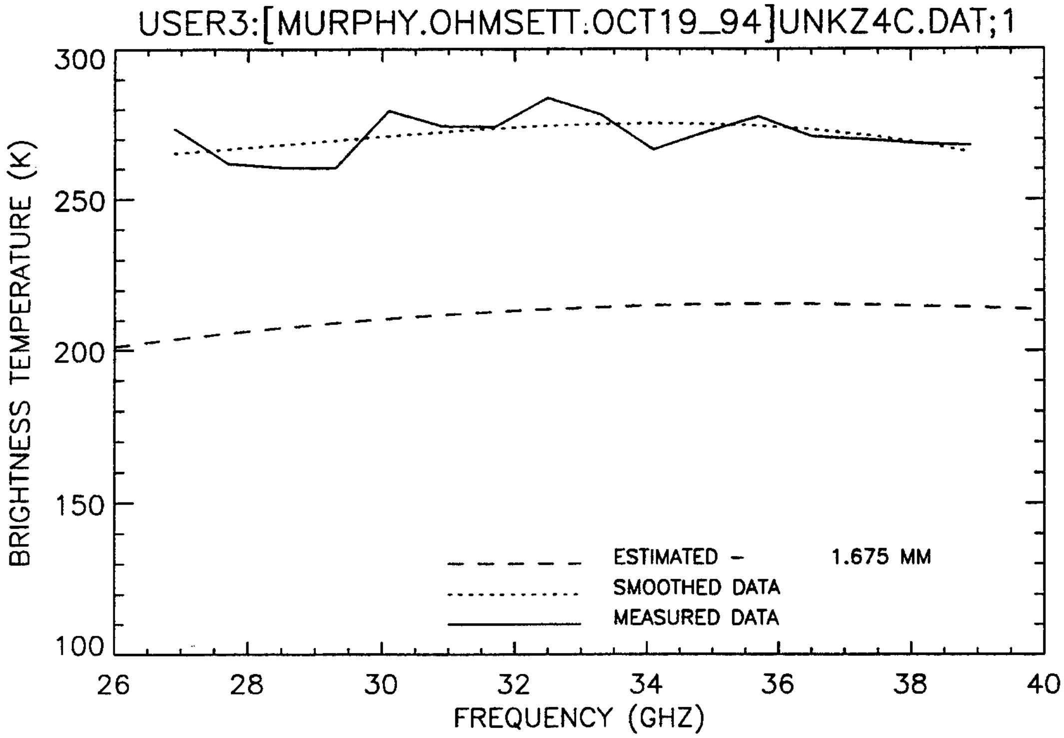

Figure G-125 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 4, Chop Condition 2, 19 October 1994, Pass 3

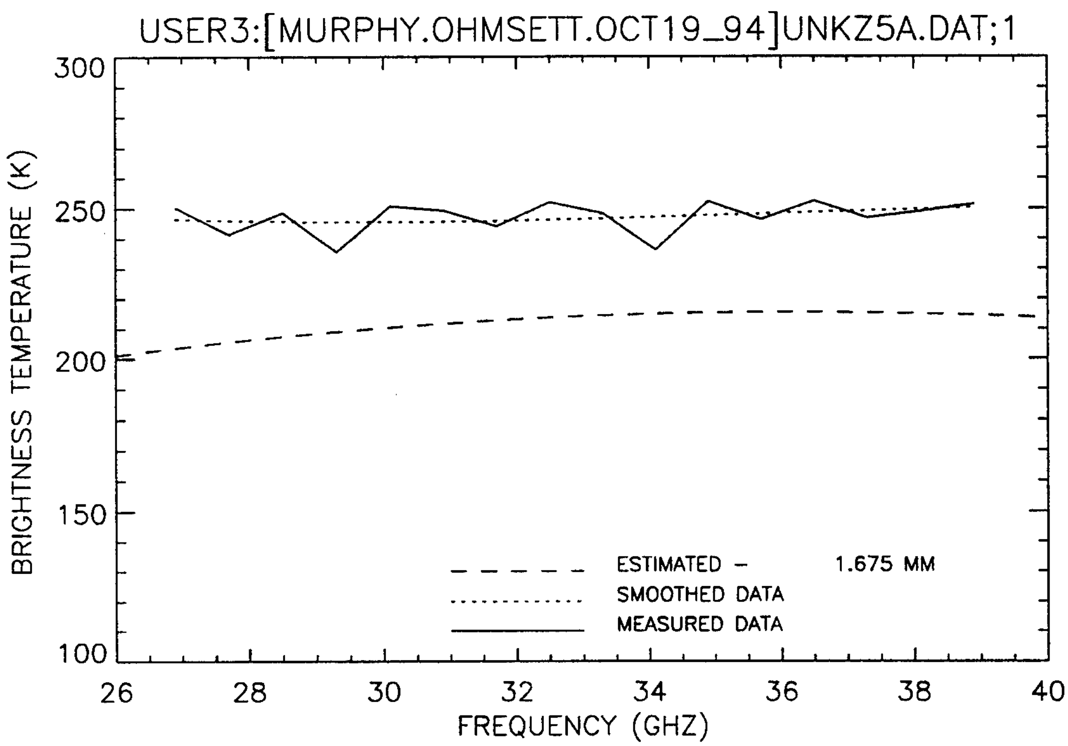

Figure G-126 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, Chop Condition 2, 19 October 1994, Pass 1

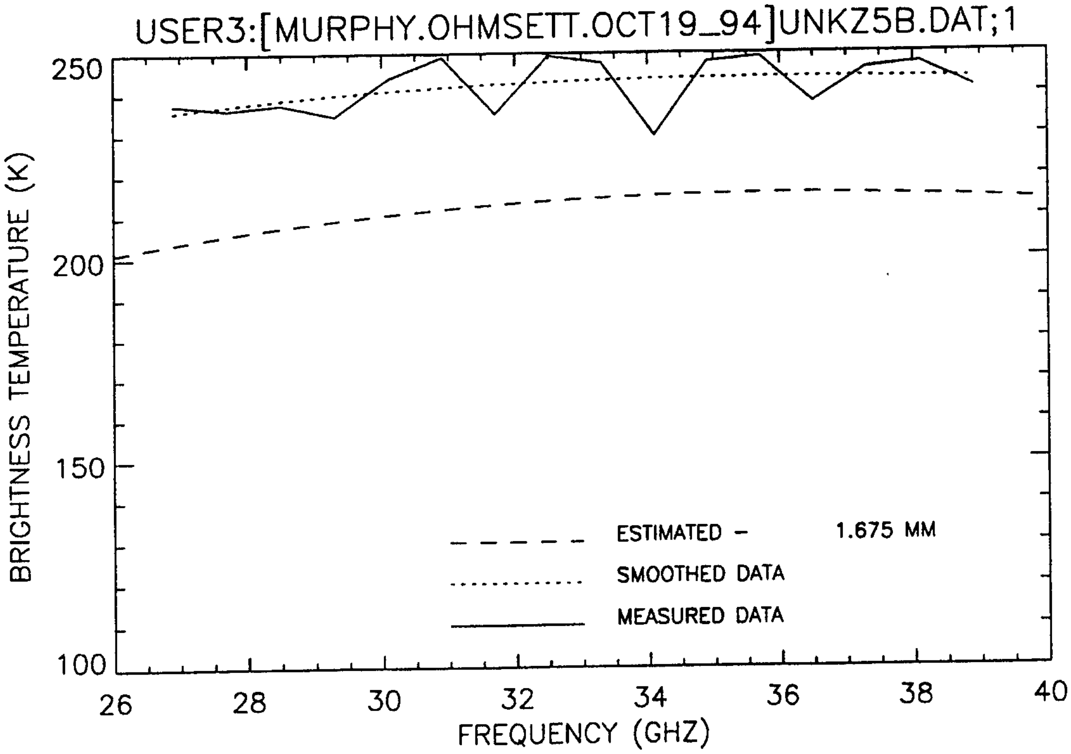

Figure G-127 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, Chop Condition 2, 19 October 1994, Pass 2

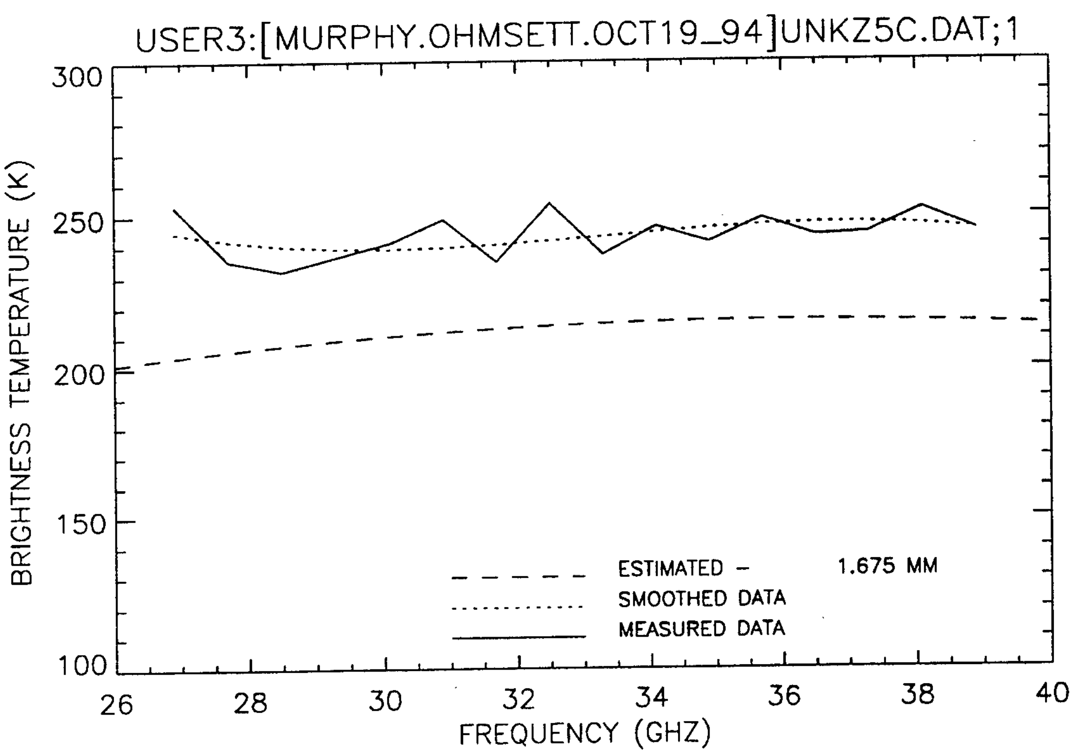

Figure G-128 T^B Versus Frequency Plot for "Unknowns" Measurement, Pool 5, Chop Condition 2, 19 October 1994, Pass 3

APPENDIX H

BRIGHTNESS TEMPERATURE VERSUS FREQUENCY PLOTS FROM OHMSETT "FLYING" TESTS

The frequency scanning radiometer was set up at the OHMSETT facility on the main equipment bridge with the oil pools in the radiometer antenna field of view. Tests were conducted on 14 October over the dyed diesel oil pools and again on 19 October over the oil pools of unknown thickness. All of the measurements were collected under calm conditions.

The plots shown in this appendix, figures H-1 through H-6, are radiometric brightness temperature (T^B), expressed in Kelvin (K), as measured by the FSR, versus the measurement frequency in GHz. Under the current FSR software configuration, sixteen equally spaced points between 26.5 GHz and 40.0 GHz are sampled, with each sample period somewhat less than one second. These sixteen points are plotted as 'measured' points. For each data set, the oil thickness estimation algorithm, described in Chapter 4, is used to estimate an oil film thickness. This algorithm derived estimate is displayed with the smoothed curve and the declared result plotted over the actual measured points. The data analyst can then either choose to accept the algorithm estimate, or manually select a curve that may be a better fit to the measured data. Comments are provided for each measurement concerning the fit of the algorithm estimate and the analyst's choice for each curve's best fit.

The plots in this appendix are arranged by test session. At the beginning of each test session data set, comments are provided for each measurement concerning the fit of the algorithm estimate and the analyst's choice for each curve's best fit.

When viewing the plots, it is important to understand that the figure titles cite only the <u>target</u> oil thickness value within the test pool being viewed. As described in chapter 3, the actual thickness of oil being viewed by the FSR at any given moment could vary substantially from this target value.

The water reference file that was used for this set of comparisons is H101400C.dat. The OHMSETT main bridge was set to move at a velocity of 0.172 m/s and data was collected as the FSR passed over the target pools containing 2.0 mm thick oil, 3.0 mm thick oil and 8.0 mm thick oil. Only the 2.0 mm oil target exhibited a non-uniform coverage as described below.

FLY2 - This curve is an excellent match to the algorithm estimate of 2.775 mm. The oil target visually appeared slightly thicker on the north side of the pool compared to the south side. The surface of the oil seemed to contain some type of dust or pollen. The calm condition measurements (stationary bridge) ranged from 2.275 mm to 3.350 mm; however, some difficulties in estimating thickness were encountered while measuring the oil target under (stationary) calm wave conditions.

FLY3 - This curve is an excellent match to the algorithm estimate of 3.500 mm. The calm condition measurements (stationary bridge) for this oil target ranged from 3.300 mm to 4.225 mm.

FLY8 - This curve is a good match to the algorithm estimate of 8.5 mm. The smoothed data curve does not peak as high as the theoretical prediction would estimate; however, there are some actual measured data points near the peak of the curve. The curve fitting technique for the smoothed curve uses a third-order polynomial fit. Because the curves for thicker oil films are sinusoidal, the third-order polynomial curve fit to the measured points may not be the optimal choice, but is adequate for the purposes of this report. The calm condition measurements (stationary bridge) for this oil target ranged from 8.600 mm to 8.825 mm.

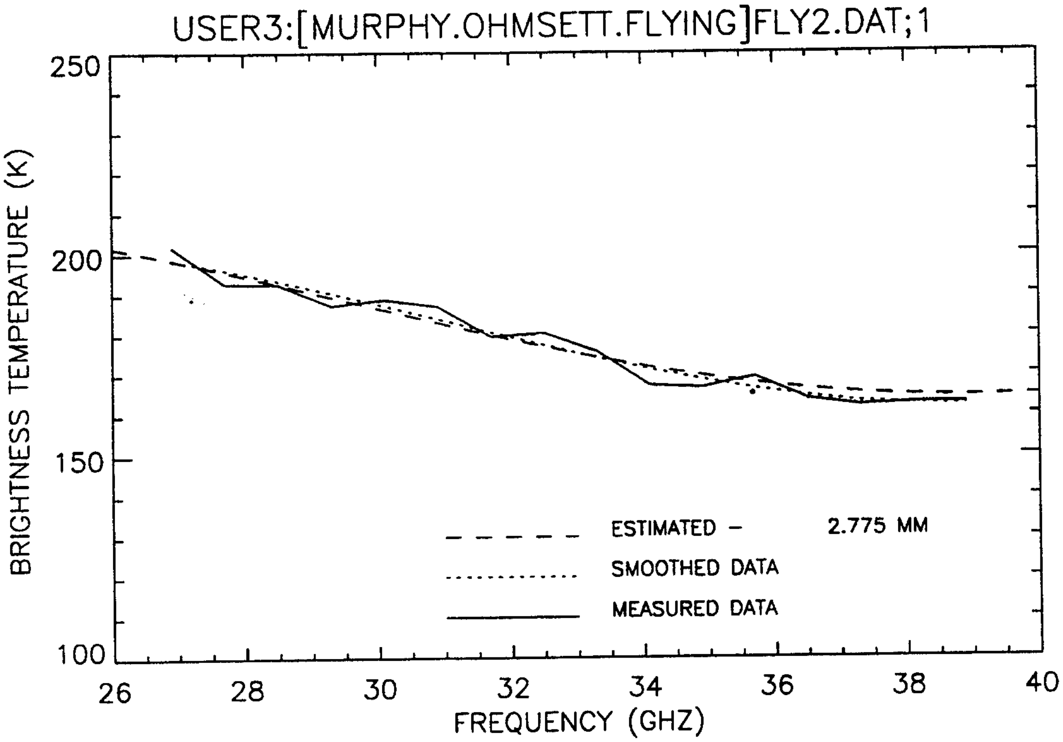

Figure H-1 T^B Versus Frequency Plot for Flying Measurement, 14 October 1994, Dyed Diesel, 2.0 mm Pool

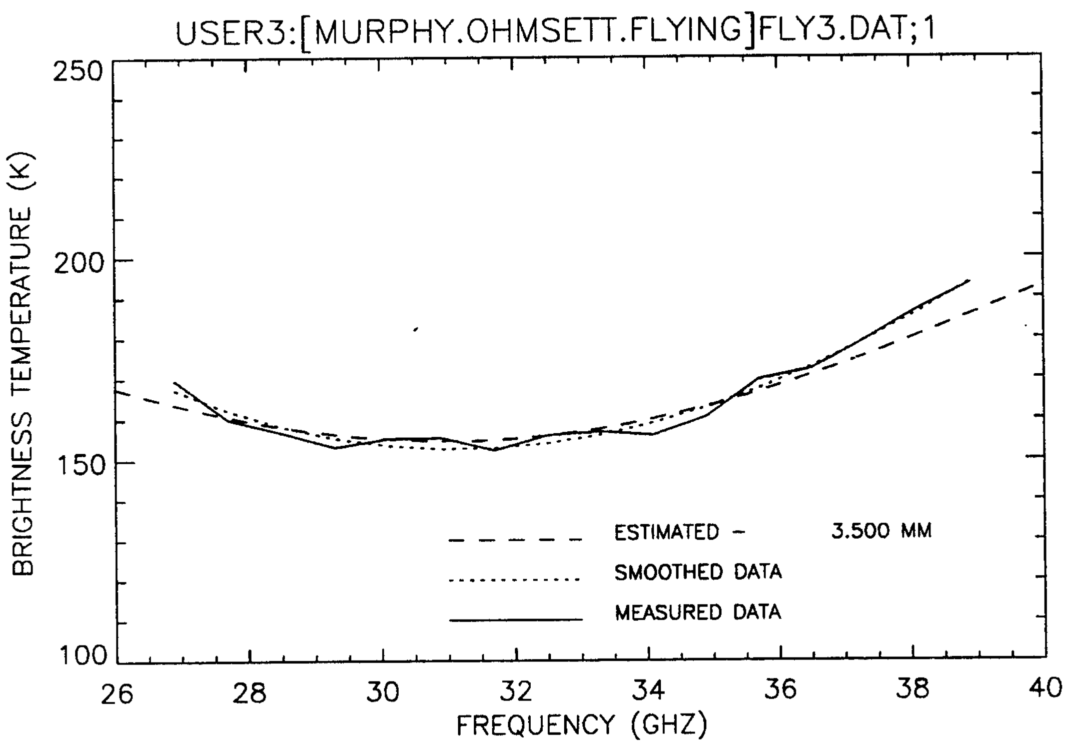

Figure H-2 T^B Versus Frequency Plot for Flying Measurement, 14 October 1994, Dyed Diesel, 3.0 mm Pool

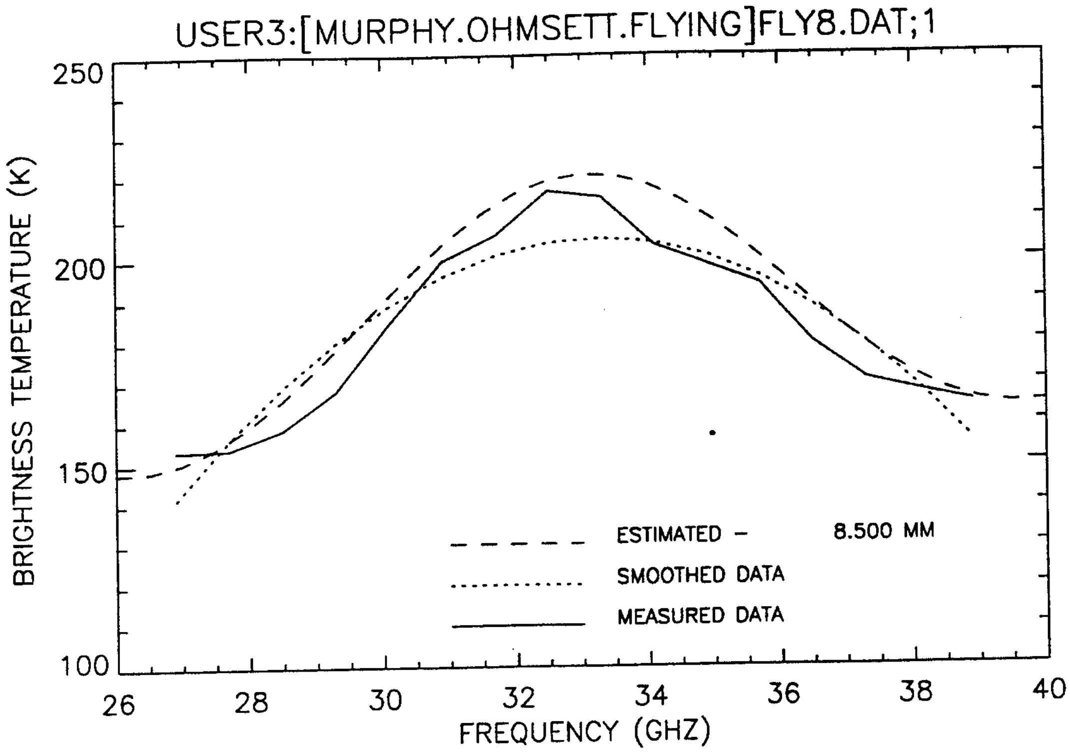

Figure H-3 T^B Versus Frequency Plot for Flying Measurement, 14 October 1994, Dyed Diesel, 8.0 mm Pool

The water reference file for these measurements is UNKREFB. The OHMSETT bridge was set to move at a velocity of 0.27 m/s over the oil target pools. Measurements were collected over pools 4 and 2 under calm conditions.

The surface of unknown pool 4 had a swirly area of partially mixed oil nearly in the center of the containment area. Calm condition measurements taken earlier in the day had identified this part of the oil target as emulsion. The other parts of the oil target seemed well mixed, with no obvious inclusions; these areas were estimated to be 1.4 - 1.6 mm thick oil.

FLYA4A - This curve is a poor match to the algorithm estimate of 1.700 mm. Because the T^B is in the range from 200 K to 250 K, the curve suggests the presence of bubbles or emulsion; however, the shape of the curve seems to match an estimate of 5.2 mm. This may indicate a low water percentage (by volume) emulsion that is actually 5.2 mm in thickness. The calm condition measurements (stationary bridge) for this oil target ranged from 1.400 mm to 1.600 mm over the non-swirly area; over the swirly patch the measurements indicated bubbles or emulsion. The OHMSETT reported thickness was 1.6 mm of a mixture of waste oil and diesel oil, with 60% surface coverage within the oil containment area.

FLYA4B - This curve is a poor match to the algorithm estimate of 1.725 mm. Because the T^B is in the range from 200 K to 250 K, the curve suggests the presence of bubbles or emulsion; however, the shape of the curve seems to match an estimate of 5.2 mm. This may indicate a low water percentage (by volume) emulsion that is actually 5.2 mm in thickness. The calm condition measurements (stationary bridge) for this oil target ranged from 1.400 mm to 1.600 mm over the non-swirly area; over the swirly patch the measurements indicated bubbles or emulsion.. The OHMSETT reported thickness was 1.6 mm of a mixture of waste oil and diesel oil, with 60% surface coverage within the oil containment area.

FLYA2A - This curve is a good match to the algorithm estimate of 3.25 mm. The calm condition measurements (stationary bridge) for this oil target ranged from 3.250 mm to 3.875 mm. The OHMSETT reported thickness was 2.6 mm of diesel oil with 100% surface coverage within the oil containment area. Visually, this target appeared to have a uniform thickness over the entire containment area.

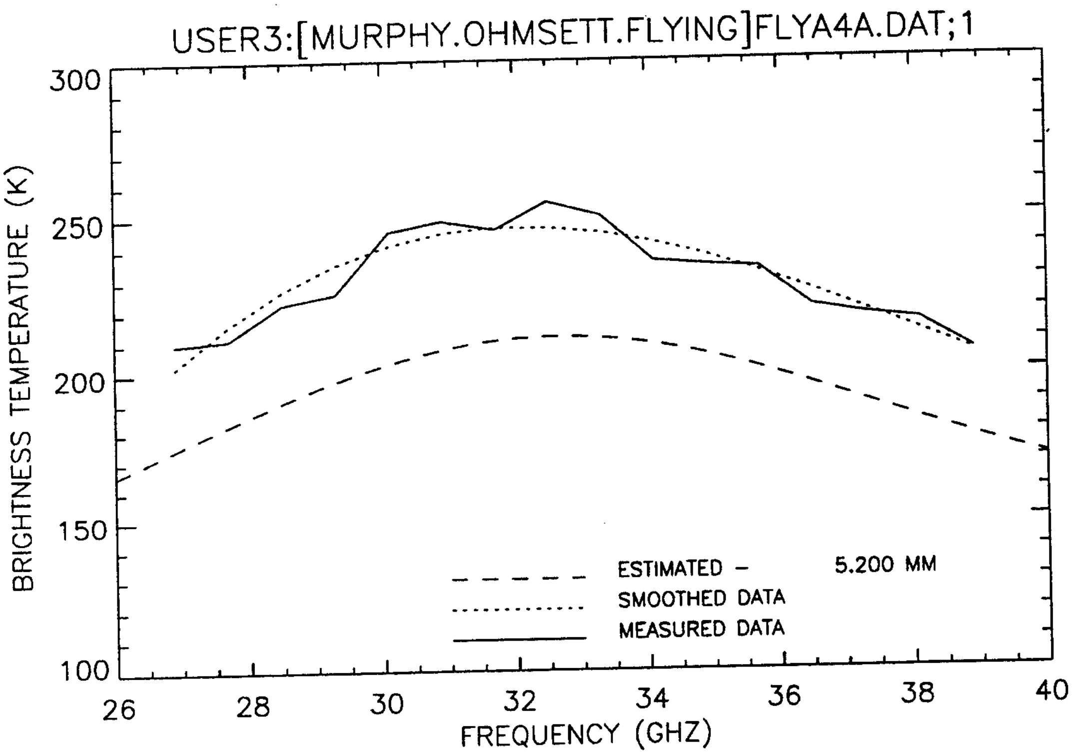

Figure H-4 T^B Versus Frequency Plot for Flying Measurement, 19 October 1994, "Unknown" pool 4, Pass 1

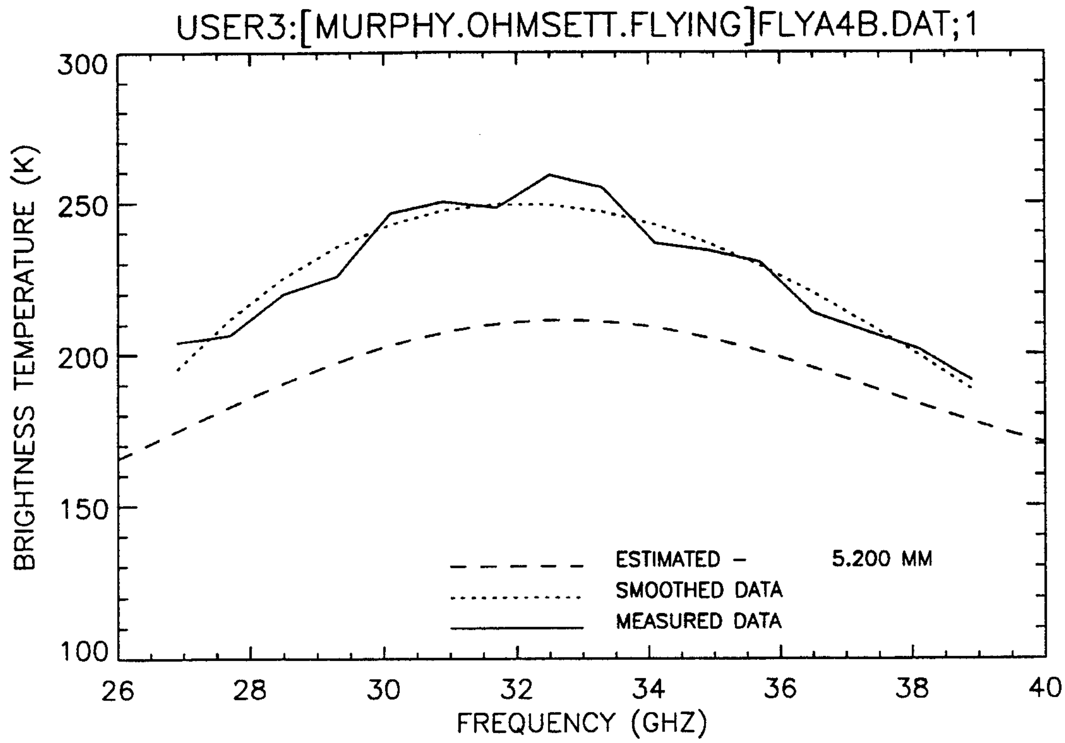

Figure H-5 T^B Versus Frequency Plot for Flying Measurement, 19 October 1994, "Unknown" pool 4, Pass 2

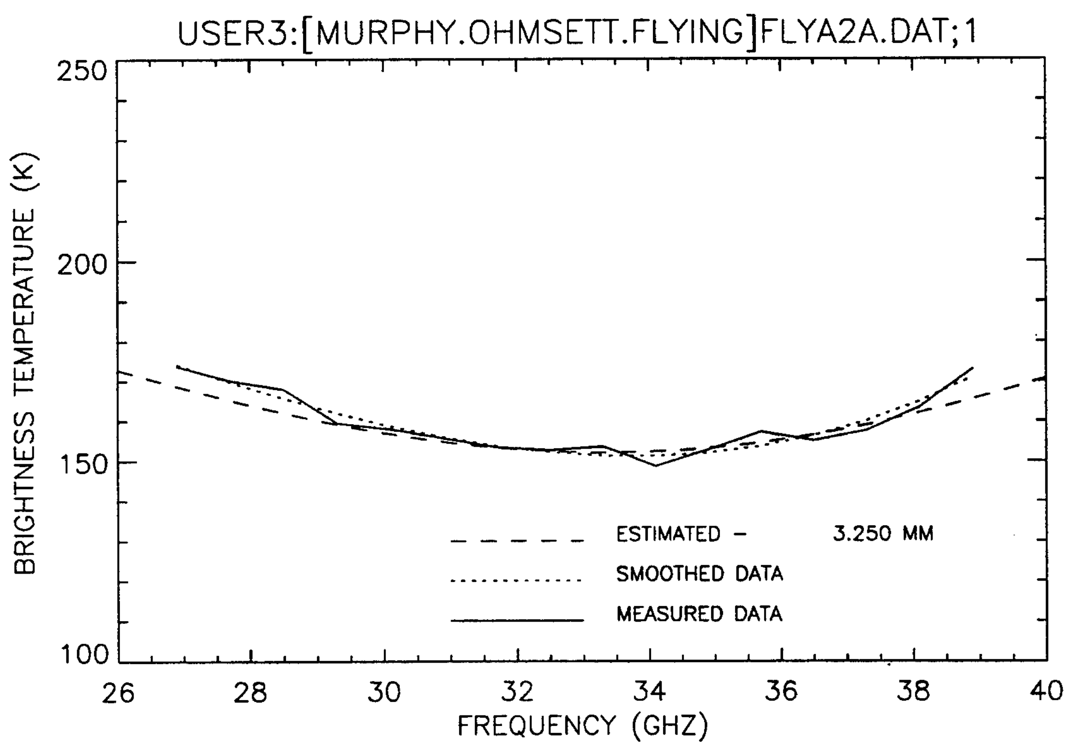

Figure H-6 T^B Versus Frequency Plot for Flying Measurement, 19 October 1994, "Unknown" pool 2, Pass 1

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